**MODELING THE IMACT OF LAND USE/LANDCOVER DYNAMICS ON STREAM FLOW AND SEDIMENT YIELD:**

A CASE STUDY OF UPPER AWASH BASIN

A thesis submitted to the Graduate Program (CACE) in partial fulfillment for the award of the degree of Master of Science in Civil Engineering (Hydraulic)

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I, the undersigned, certifies that I read and hereby recommend for acceptance by the Addis Ababa Science and Technology University a thesis entitled " Modeling the Impact of Land use/Land cover Dynamics on Stream Flow and Sediment Yield: A Case Study of Upper Awash Basin*"* in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Major: Hydraulic Engineering).

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**ABSTRACT**

*The population growth, deforestation and urban area expansion for the last 30 years cause's changes in land use/cover of Upper Awash basin. The effect of land use/cover changes have impacted the stream flow and sediment yield of the watershed. The knowledge of how land use/land cover change influence on watershed hydrology will enable local government and policy makers to formulate and implement effective and appropriate response strategies to minimize the undesirable effect of future land use/land cover change or modification. In this research SWAT model was used for analyzing the land use/cover changes on the hydrology of the watershed (stream flow and sediment yield) and its impact on reservoir sedimentation. Model calibration and validation was done at Hombole station. For 1990 and 2013 land use/cover change calibration and validation was 1990-2007 and 2008-2014 respectively. Result from both land use/cover show acceptable range, 0.72-0.89 for $R^2$, 0.7-0.83 for NSE. The impact of land use/cover change was analyzed by using three criteria; the first was by selecting sub basin with the highest surface runoff and sediment yield. The second was by selecting the lowest surface runoff and sediment yield, and the last one was by selecting sub basin, which had different land use/cover using 1990 and 2013 land use/cover map. The model estimated stream flow and sediment yield from Upper Awash Basin for both 1990 and 2013 land use/cover maps. Therefore, 45.05 m3/s of stream flow and 57.06 Mtone annual sediment yield were entered to Koka dam during 1990 and 66.56 m3/s of stream flow and 47.36 Mtone annual sediment yield was extracted from the upper awash basin during 2013 land use/land cover data. During this period agricultural land was decreased by 28%, natural forest land decrease by 47.78%. In addition, urban area was increased by 166%, while plantation area appeared to be highly increased. The result obtained shows that there is 47.75 % increment of stream flow and 17 % decrement of sediment yield in 2013 as compared to 1990 land use/land cover data.*

*Key words: Land use/land cover, Upper Awash basin, SWAT, stream flow, sedimentation, calibration and validation*

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Dedicated

To

My family in love

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AgNPS | Agricultural Non-Point Source |
| ANN | Artificial Neural Network |
| CN | Curve Number |
| DEM | Digital Elevation Model |
| FAO | Food and Agricultural Organization |
| GIS | Geographic Information System |
| HBV | Hydrologiska Byrans Vattenbalansavdelning |
| HRU | Hydrologic Response Unit |
| HSPF | Hydrologic Simulation Programme-Fortran |
| IWMI | International Water Management Institute |
| LM | Luvenberurg Multiquadrant |
| LULC | Land Use Land Cover |
| M..a.s.l. | Mean at sea level |
| MLP | Multi-Layer Perceptron |
| MoWIE | Ministry of Water, Irrigation and Energy |
| NMA | National Metrological Agency |
| PBIAS | Percent Bias |
| PE | Processing Element |
| NSE | Nash Sutcliffe Efficiency |
| RBNN | Radial Basis Neural Network |
| RSR | Root mean Square error observation standard deviation Ratio |
| SCS | Soil Conservation Service |
| SWAT | Soil and Water Assessment Tool |
| UNESCO | United Nations Education, Science and Culture Organization |
| USLE | Universal Soil Loss Equation |
| MUSLE | Modified Universal Soil Loss equation |
| WEPP | Water Erosion Prediction Model |
| WXGEN | Weather Generator |

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# CHAPTER ONE

## 1 INTRODUCTION

### 1.1 Background

Land use change is ubiquitous drivers of global environmental change. Impact assessments frequently show that interactions between climate and land use change can create serious challenges for aquatic ecosystems, water quality, and air. For instance, the changes in land -cover have affected the surface and groundwater hydrology and altering the hydrological cycle (Skaggs et al., 2006; Sun et al., 2004). These effects vary as functions of seasonality and the changing climate (Huxman, et al, 2005). Hence, it might be appropriate to analyze land use/land cover and crucial to know the effects of land use change on catchment hydrology for sound land use planning and water resource management.

Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients. So far, limited measures have been taken to combat these problems. In this study a physically based watershed model, SWAT was applied to the Upper Awash basin of Ethiopia for modeling hydrology of the study area. The main objective of this study will be to model the impact of land use / land cover dynamics on stream flow and sediment yield. Ethiopia experiences persistent land, water and environmental degradation due to localized and global climatic anomalies. These leave the country to recurrent crop failures and severe food shortages. Low soil fertility coupled with temporal imbalance in the distribution of rainfall and the substantial non-availability of the required water at the required period are the principal contributing factors to the low and declining agricultural productivity. Hence, proper utilization of the available soil and water resources is essential to Ethiopia's agricultural development and achievement of food security.

Establishing a relationship along various environmental parameters is the central focus of hydrological modeling from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equation. Models are generally used as efficacy in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as land use change, climate change, deforestation and change of watershed management (intervention of watershed conservation practices). Poor land use practice and improper management system has played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients. So far, limited measures have been taken to combat the problems. In this study, a physically based hydrological model will be applied for modeling the runoff and sediment yield.

The distributed hydrological models, (Zhi L et al., 2009) were using Soil and Water Assessment Tool (SWAT) model to examine the impact of land use and climate change on Soil erosion and Stream flow. They found that the climate effect is dominant in stream flow than soil erosion. While land-cover change may have a moderate impact on stream flow, it strongly influences soil erosion. Despite these facts, it is important to apply SWAT model for analyzing the impact of land use and land cover change on environmental degradation, including soil erosion, water management and reservoir sedimentation.

Given that impacts of land use/cover change on water resources are the result of complex interactions between diverse site-specific factors and offsite conditions, standardized types of responses will rarely be adequate. General statements about land–water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2002). Land and water resources degradation are the major problems in the Ethiopian highlands. The dynamics of the hydrological process altered as watershed landscapes are increasingly modified for agricultural and urban uses. As a result of runoff from rainfall, soil particles on the surface of a watershed can be eroded and transported through the processes of sheet, rill, and gully erosion. Once eroded, sediment particles are transported through a river system and are eventually deposited in reservoirs, or in lakes. Besides the above factors, physical changes resulting from urbanization also affects the water budget through, reduction of interception of rainfall due to removal of trees, removal of natural vegetation and change in the drainage patterns, loss of natural depressions which temporarily store surface water (i.e. regarding of areas results in a change in topography), loss of rainfall absorbing capacity of humus on the forest floor, and Creation of impervious surfaces (rooftops, roads, sidewalks, driveways, etc.)

In situations of rapid and often unrecorded land use change, observations of the earth from space provide objective information of human utilization of the landscape. Over the past years, data from Earth sensing satellites have become vital in mapping the Earth's features and infrastructures, managing natural resources and studying environmental change.

Hydrological models provide an alternative solution. There are two basic advantages using hydrological models. In the first place, models can be used to understand the processes that are difficult to measure due to the complexity of temporal and/or spatial scale. Secondly, a model can be used to study the effect of changes in land cover, water management or climate

The Awash basin has a total area of 110,000 km$^2$. The basin is divided in two; Western catchment of 64,000 km$^2$ and ester catchment 46,000 km$^2$ with only western catchment contributing to the main river flow. The eastern catchment drains to desert area. The study area is found in the tributaries of Awash 8.5$^o$ N to 12$^o$ N. The average basin slope ranges from 0.7 % to 23.5 % and it has an elevation range of 1584m a.s.l to 3576m a.s.l.

Given that the impact of land use/cover change on water resource are the result of complex interaction between diverse site-specific factors and offsite conditions, standardize types of responses will rarely be adequate. General statement about land-water interaction need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making process (FAO, 2002). Thus, this study will be conducted to determine the effect of land use pattern on surface runoff and sediment yield in the basin using the SWAT model

## 1.2 Statement of the problem

Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. Many farmers in Ethiopia highlands cultivate sloppy or hilly land, causing top soil to be washed away during the torrential rains of the rainy season. With the fast growing population, there is pressure on land resource, resulting in even forest clearing and overgrazing.

Koka dam was constructed on the Awash River, which originates from the highlands and is characterized by high peak flash floods, which carry lots of sediment. It can thus be anticipated that the water storage of the reservoir is subject to sever problem of siltation. Three sedimentation surveys have been carried out on Koka reservoir previously. From these surveys, it was concluded that the average rate of sedimentation in the reservoir is in the order of 25Mm3 per annum (Halcrow, 1989). Thus, rapid land use/cover changes caused by clearing of the forest for agricultural production and settlement are presumed adversely affect the hydrological response of the upper awash basin.

This study introduces the dynamics in land use/cover of upper awash basin and its effect on surface runoff and sedimentation.

## 1.3 Research questions

- ✓ How well can SWAT simulates stream flow and sediment yield in the catchment?
- ✓ How does land use and land cover change affects the stream flow and sediment yield of the Basin?
- ✓ How much sediment will flow to Koka dam?
- ✓ Which sub watersheds produce more sediment yield?
- ✓ How can the land use and land cover change affects stream flow and sediment yield?

## 1.4 Objectives

The main objective of this research is to model the impact of land use / land cover dynamics on stream flow and sediment yield for upper Awash Basin.

Specific Objectives

- ✓ To establish spatial variability of sediment yield and identify erosion risk area of the basin
- ✓ To estimating the annual sediment yield loading to Koka dam
- ✓ To assess the impact of land use land cover change on stream flow and sediment yield by using 1990 and 2013 LU/LC maps.

## 1.5 Significance of the study

Reasonable prediction of stream flow and sediment transport is essential for developing watershed management plans. It is important for knowing the hydrologic behavior of river basins within modeling frameworks, so that future assessments on hydrologic behavior of the watershed will be attained.

The previous studies of the area showed that the basin has a substantial potential for irrigation. The estimated land area suitable for irrigation is about 205,400 ha, 4.7% of irrigable area in the country (Taddese et al., 2012)

In order to attain and go through to those potential capacity of the basin, this study will be used as an input for designer and policy maker to take appropriate measures or implement effective land and water management interventions to reduce on site and off site impact of erosion (engineering conservation measures, silt retention micro dams and design of water harvesting structures in the watershed) and the modeling approach conducted will be used as an input for scenario development for any hydrologic works in the study area to use appropriate tool considering time and space.

## 1.6 Scope of the study

The study mainly focuses on application of SWAT model for the Upper Awash basin for characterization of stream flow and sediment yield. Model efficiency valuation and quantification of sediment yield and surface runoff identification of sensitive areas of the watershed by SWAT model, planning & designing water resource potential for different purposes in the catchment.

## 1.7 Thesis out line

This thesis contains five chapter and organized as follows: Chapter one is an introduction to the study. Chapter two reports on the literature review about the subject matter and Chapter three describes materials and methods applied. In chapter four, the results are shown and discussed. Chapter five finalizes the thesis by conclusion and recommendation.

## CHAPTER TWO

# 2 LITRATURE REVIEW

## 2.1 Land use and land cover dynamics

Land cover has gone under continuous change for millennia. This change has occurred through the use of fire for game hunting and clearance of patches of land for agriculture and livestock production, since the advent of plant and animal domestication. This is because human production demands cannot be fulfilled without modification and/or conversion of land covers. In the past two centuries, the impact of human activities on land has grown enormously because of population increase, technological development and the requirements thereafter, altering entire landscapes, and ultimately affecting the biodiversity, nutrients and hydrological cycle as well as climate (de Sherbinin, 2002) especially in the developing world. These diverse roles have been recognized in a large number of research publication and international conferences, symposia, and workshops devoted to the subject over the past few years.

According to de Sherbinin (2002), land use is the term that is used to describe human uses of land, or immediate actions modifying or converting land cover. On the other hand, land cover refers to the natural vegetative cover types that characterize a particular area. Land use change is the proximate cause of land cover change. The driving forces to this activity could be economic, technological, scenic and or other factors. Hence, land use land cover dynamics is a result of complex interaction between several biophysical and socio-economic condition, which may occur at various temporal and spatial scale (Reid et al., 2000)

## 2.2 Interaction of land use land cover and hydrology

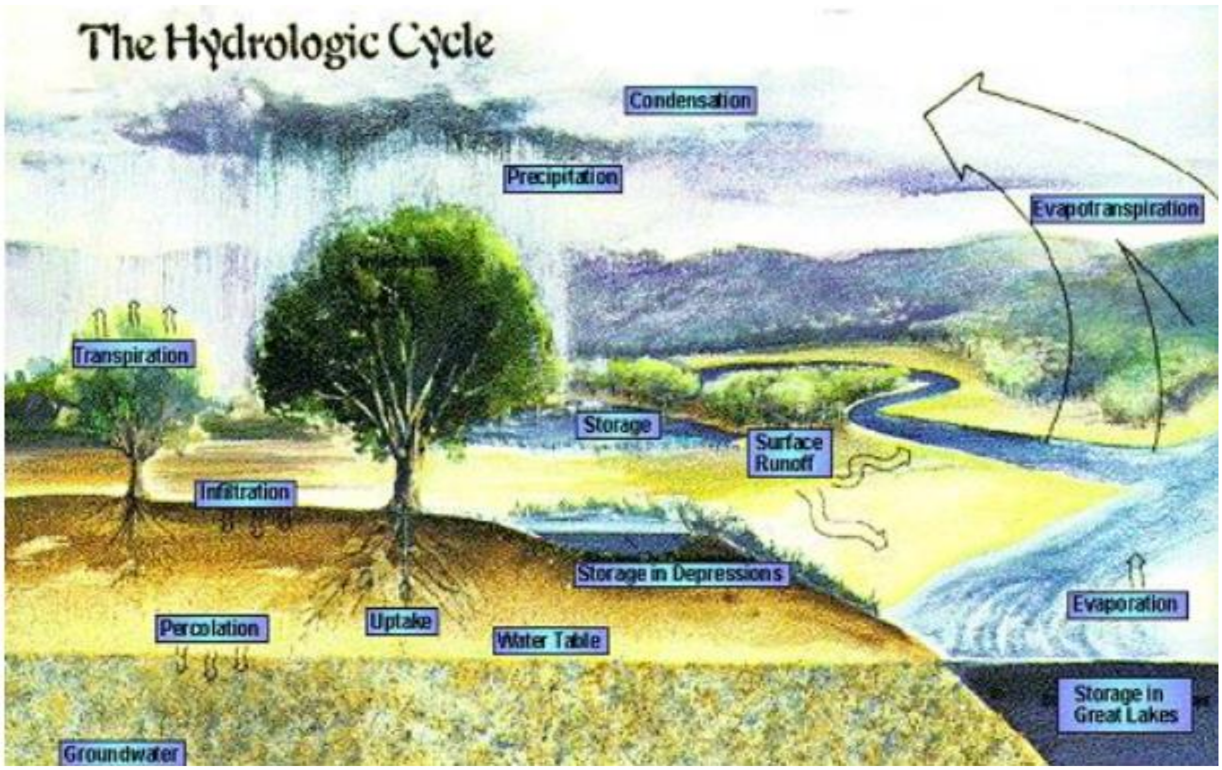
Human activities such as agriculture and urban development affect land cover and land use. Land cover is the biophysical state of the earth's surface and immediate subsurface, which include: Biota, Soil, topography, surface and underground water, and human structures (Hartemink et al., 2006) The land use involves the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation for which the land is used (Lambadin et al., 2003; Hartemink et al., 2006) Land use and land cover are significant in catchment studies specially in assessing environmental change. The environment impact at local, regional levels Significantly affect hydrological response of a catchment. Alteration in the earth's surface have major implication for the radiation balance, complexity and, water quality and quantity, surface run off dynamics, lowering of ground water tables (Lawal, 2004; Mungai *et al*., 2004). Furthermore, vegetation modification, whether resulting from harvesting or planting, alters the water balance of the site. This may eventually alter the hydrologic regime of the catchment. If vegetation is significantly reduced the flow path of precipitation can be altered and significant surface flow can take place causing erosion, and sedimentation of water bodies. Some work by Golosov and panin (2006) showed that the hydrologic regime and sediment flux change drastically following the farming activities within a basin. Cultivation of land exerts a major influence on the relationship between surface and subsurface flow. Annual surface runoff from from a loam soil increases by four times in cultivated catchments, according to data from long-term observation done in paired catchments in the forest zone of Central Russia (Golosov V. and Panin A., 2006). Surface runoff is extremely limited under grass or forest vegetation compared with agricultural land.

Hydrological effects of land use and cover change are manifested in many ways and at different spatial and temporal scale. Most obvious is the immediate and direct effects on the quantity and quality of catchment's runoff. For instant, land cover change is the most significant driving hydrologic changes such as runoff volume, timing and variability (Foherer et al., Maingi and Marsh, 2001; Miller et al., 2002; Donner, 2004). The simplest method to assess these effects on hydrologic response of a catchment is by comparing stream flow and run off generated from the catchment areas with the contrasting land use types (Barkhordari.J, 2003).The main concern is with the direct and local effect of land use change on hydrology with in a catchment level (Maidment, 1993). Catchment land use change is always due to natural and man-causes, where the man-made causes are mainly attribute to the search for resource to meet human needs. For instant deforestation is resultant of the need for timber for construction, fuel wood, and clearing for agricultural development and for settling the ever-increasing population (Chemelil, 1995). The need for fertile land to meet the ever-increasing demand for food has left the natural population with no option but to clear the natural and artificial forested areas for agriculture development (Maingi, J. k. and Marsh, S. E., 2001). As the landscape in a catchment is altered in both space and time, the factor that influence hydrologic response of the catchment also change (Singh, P. V. and Fiorentino M., 1996). The evaluation of the relationship between the land use and land cover is important for the efficient catchment management. This evaluation has normally been done using several types of models that vary from strictly empirical to physically based distributed models (Barkhordari.J, 2003). Physically distributed models in particular need specific data on land use and soil types and their location within a catchment (Chakraborty et al., 2005).

## 2.3 Hydrological process

Water on earth exists in a space called the hydrosphere which extends about 15km up in to the atmosphere and about 1km down in to the lithosphere, the crust of the earth (Chow et al, 1988). Water circulates in the hydrosphere through the maze of paths constituting the hydrological cycle. As shown schematically in Fig. 3.1, water evaporates from the ocean and the land surface to become part of the atmosphere; water vapor is transported and lifted in the atmosphere until it condenses and precipitates on the land or the ocean; precipitated water may be intercepted by vegetation, become overland flow over the ground surface, infiltrate in to the ground, flow through the soil as subsurface flow, and discharge in to streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge ground water, later emerging in springs or seeping into streams to form surface runoff, and finally flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continues.

Although the concept of the hydrologic cycle is simple, the phenomenon is enormously complex and intricate. It is not just one large cycle but is rather is composed of many interrelated cycle of continental, regional, and local extent. Although the total volume of water in the global hydrologic cycle remains essentially constant, the distribution of this water is continually changing on continents, in regions, and within the local drainage basin. The hydrology of a region is determined by its weather patterns and by physical factors such as topography, geology and vegetation. Also, as civilization progresses, human activities gradually encroach on the natural water environment, altering the dynamic equilibrium of the hydrologic cycle and initiating new process and events.




[Source: Institute of Water Research, Michigan State University, 1997]

Figure 2.1 Hydrological process

Changes in distribution, circulation, quality or temperature of earths water, which have far reaching, effects may be caused by human activities. People till the soil, irrigate crops, fertilize land, clear forested, pumps ground water, build dams, dump waste in to rivers and lakes, and do many other constructive and destructive things that affect the circulation and quality of water in nature.

## 2.4 Hydrological model

Modeling is defined as the process of organizing, synthesizing, and integrating component parts into a realistic representation of the prototype. (USDA, 1972) Lists the following benefits of modeling: Models help sharpen the definition of hypotheses, define and categorize the state of knowledge, provide an analytical mechanism for studying the system of interest, and can be used to simulate experiments instead of conducting the experiments on the watershed itself.

Hydrological models are characterizations of the real world system. Modeling of the rainfall runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, 1985). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to ungauged catchments and into the future to assess the likely impact of future hydrological changes. A wide range of hydrological models are used by the researchers, however, the applications of those models are highly dependent on the purposes for which the modeling is made. (Beven, 1985). Stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models, it is very important to understand how the catchment responds to rainfall under different conditions.

### 2.4.1 Types of Hydrological Models

**Lumped models**: Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area-weighted average (Haan et al, 1994). Lumped models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, 1985).

**Semi-distributed models**: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven, 1985). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin.

**Distributed models**: Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

Therefore, spatially distributed models are the best way towards understanding the impact of land use and land cover changes rather than the lumped ones. Hence, the following spatially distributed models are fall in to consideration during model selection period.

### 2.4.2 HBV-96

The HBV-model (Hydrologiska Byrans Vattenbalansavdelning) is a general purpose hydrologic model developed at Swedish Metrological and Hydrologic Institute (SHMI).

The model is designed to run on a daily time step (shorter time steps are available as an option) and to simulate river runoff in a river basin of various sizes. The basin can be disaggregated in to sub basins, elevation zones, and land cover types. Input data include precipitation, air temperature (if snow is present), monthly estimate of evapotranspiration, runoff (for calibration) and basin geographical information. The treatment of snow accumulation and melt in HBV is based on a simple accounting (degree-day) algorism. The existence and amount of snowfall is predicted using metrological input data extrapolated to the mean elevation of each sub-area of the basin. A simple model based on bucket theory is used to represent soil moisture dynamics. There is a provision for channel routing of runoff from tributary basins, using a modified Muskingum method. Outflow from lakes is usually specified by a stage-discharge rating curve but can be given by a lookup table to allow for power station operating rule. The HBV model can be linked with real time weather information and river monitoring system (Lindstorm et al., 1997).

### 2.4.3 HEC-HMS (Hydrologic Modeling System)

HMS is a comprehensive hydrologic model developed by Hydrologic Engineering Center (HEC) of United States Army Corps of Engineers (USACE). It is event-based model (HEC, 2000). HMS offers several options to model various physical processes occurring in a watershed system. One such process is the direct runoff computations. Most of runoff models available with HMS are lumped in nature except for two which are distributed. Most of the lumped runoff models derive their roots from the unit hydrograph (UH) concept.

The model provides a lumped model option called Clark's UH. To overcome its lumped character, a modified version called ModClark method was developed for HMS (Daniel and Arlen 1998). ModClark's method requires that watershed be further divided in to sub-areas is assigned individual lag time instead of one value for the whole watershed, as in the case of Clark's UH. The precipitation excess at each sub area is transported to the watershed outlet using the corresponding lag time. Thus the inflow contributions due to all the subareas to linear reservoir are computed. These flows are then routed through a linear reservoir (only a single value for storage coefficient being defined for all the sub areas) to obtain the hydrograph at the outlet, which will later be routed through the channel.

### 2.4.4 TOPMODEL

TOPMODEL is a hydrologic model that bases its distributed predictions on an analysis of basin topography. The development of TOPMODEL was initiated by Michael Kirkby at the school of Geography, University of Leeds. The model allows basin to be divided into a set of sub basins. Evaporation is estimated by the Penman-Monteith method. Surface runoff is computed based on variable saturated areas.

The subsurface flow is calculated using an exponential function of water content in the saturated zone. Channel routing and infiltration excess are calculated using the Beven and Kirkby method. The spatial component requires a high quality DEM without sinks (Beven etal. (1997).

### 2.4.5 SWAT

SWAT is the acronym for Soil and Water Assessment Tool to a river basin, or watershed scale model developed by Dr Jeff Arnold for USDA Agricultural Research Service (ARS).

SWAT is basin scale, continuous-time model that operates on a daily time step, it is designed to predict the impact of management on water, sediment, and agricultural chemical yields in large complex watershed. The model is physically based, computationally efficient, and capable of continuous simulation of over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided in to multiple sub watersheds, which are then further sub divided in to hydrologic response unit (HRUs) that consists of homogeneous land use, management, and soil characteristics. The HRUs represent percentage of the sub watershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be sub divided in to only sub watersheds that are characterized by dominant land use, soil type, and management.

## 2.5 Model selection

The selection of a particular model is a key issue to get satisfactory answers to a given problem. Currently, there are numerous hydrological models simulating the hydrological process at different spatial and temporal scales. Although there are no clear, criteria for making a choice between models, some simple guidelines can be stated (Cunderlik, 2003). These criteria are always project-dependent, since every project has its own specific requirements and needs. Furthermore, some criteria are also user dependent (and therefore subjective), such as the personal preference for graphical user interface, computer operating system (OS), input-output (I/O) management and structure, or user's add-on expansibility.

Among project dependent criteria, there are four common and fundamentals ones that must be always answered:

- Required model outputs important to the project and therefore to be estimated by the model (does the model predict the variables required by the project such as peak flow, event volume and hydrograph, long-term sequence of flows…..),
- Hydrologic processes that need to be modeled to estimated the desire outputs adequately (is the model capable of simulating land use and land cover change,

regulated reservoir operation, snow accumulation and melt, single-event or continuous processes………),

- The availability of the input data (can all the input required by the model be provided with in the time and cost constraints of the project?),
- Price (does the investment appear to be worthwhile for the objective of the project?) (Cunderlik, 2003).

This study aims for modeling the impact of land use land cover change on the hydrology processes of upper awash basin. More specifically, the hydrologic model for this study needs to have the capability to;

- Represent variable land use land cover throughout the basin, and to produce a full hydrograph response from each sub-area
- Simulate different component of the stream flow including surface runoff, lateral flow and base flow
- Route hydrograph through different stream reaches, and identify principal runoff source area at selected point-of interest
- Compute sub-area release rates, or provide travel time and pick flow information from which these release rates may be developed.
- Evaluate the impact of land use land cover change on the hydrology
- To be applied over a range of catchment sizes from small to large catchments
- Simulate continuous and long term impact
- Freely available

For this study, SWAT is selected as an appropriate model to meet the simulation requirements set above using available soil, topography, land use land cover and weather data.

## 2.6 Description of SWAT model

Soil and Water assessment tool (SWAT) is a physically-based continuous-event hydrologic model developed to predict the impact of land management practice on water, sediment and agricultural chemical yields in large complex watershed with varying soil, land use and management conditions over long period of time (Arnold et al., 1998, 2000; Neitsch et al., 2001). It can also be used to simulate water and soil loss in agriculturally dominated small watersheds. In the SWAT model, the modeling or estimation of flow, sediment or nutrient transport of the watershed is done by dividing the watershed into sub basins and the land areas in the sub basins are also sub divided again into one or more land units, possessing similar land use, soil type and applied management strategies. These similar land units in land use, management and soil attributes are called hydrological response units (HRUs). The HRUs are helpful for better estimation of the loadings (flow, sediment, pollutants) from the sub basins.

The Arc SWAT extension of Arc GIS is a graphical interface for the SWAT model (Arnold et al., 1998). To create a SWAT dataset, the interface will need to access Arc GIS compatible raster (GRIDs) and vector datasets (shape file or feature classes) and database files which provide certain types of information about the watershed. The necessary spatial datasets and database files need to be prepared prior to running the model.

In SWAT model, the water balance is the backbone of the hydrologic simulation in a watershed; and the hydrology of the watershed can be separated into two major divisions, land phase and routing phase (Neitsch et al, 2011). Hereafter the discussion is mainly focuses on main component of SWAT model and selected options (if option selection is required) for this study. For more explanation of each component and options see SWAT 2005 model theoretical documentation (Neitsch et al., 2005a).

### 2.6.1 Land phase of the hydrological cycle

The land phase of the hydrologic processes is simulated based on the water balance equation (Neitsch et al, 2011) and computed by:

$$SWt = SWo + \sum_{i=1}^{t} (Rday - Qsurf - Ea - Wsep - Qgw) \dots\dots\dots\dots\dots\dots (2.1)$$

Where: $SW_t$ is final soil water content (mm water), $SW_o$ is initial soil water content on day I (mm), t is time (days), $R_{day}$ is the amount of precipitation on day I (mm water), $Q_{surf}$ is the amount of surface runoff on day i ( mm water), $W_{seep}$ is the amount of water entering vadose zone from the soil profile on day I ( mm water), $E_a$ amount of evapotranspiration on day i (mm water) and $Q_{gw}$ amount of return flow in day i ( mm water).

Surface runoff occur whenever the rate of precipitation exceeds the rate of infiltration. SWAT offer two methods for estimating surface runoff: the SCS curve number procedure

(USDA-SCS,1972) and the green and Ampt infiltration method (Green and Ampt,1911). Using daily or sub daily rainfall, SWAT simulates surface volume runoff volumes and peak runoff rates for each HRU.

The SCS curve number equation is (USDA-SCS,1972):

$$Qsurf = \frac{(Rday - 0.2S)^2}{Rday + 0.8S} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.2)$$

In which Qsurf is the accumulated runoff or rainfall excess (mm),

Rday is the rainfall depth for the day (mm)

S is the retention parameter (mm)

The retention parameter is defined by equation 3.

$$S = 25.4\left(\left(\frac{100}{CN}\right) - 10\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2.3)$$

Where CN is a curve number

SWAT 2005 version include two methods for calculating the retention parameter; the first one is retention parameter varies with soil profile water content and the second method is the retention parameter varies with accumulated plant evapotranspiration. The soil moisture method (equation2.4) over estimates runoff in shallow soils. But calculating daily CN as a function of evapotranspiration, the value is less dependent on soil storage and more dependent on antecedent climate.

$$S = Smax\left(1 - \frac{sw}{sw + \exp(w1 + w2sw)}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2.4)$$

In which, S is the retention parameter of a given day (mm)

Smax is the maximum value that the retention parameter can have on a given day (mm),

Sw is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point (mm), and w1and w2 are shape coefficients. The maximum retention parameter value Smax is by solving equation 3 using CN1.

$$Smax = 25.4\left(\left(\frac{100}{CN1}\right) - 10\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2.5)$$

When the retention parameter varies with plant evapotranspiration, the following equation is used to update the retention parameter at the end of every day:

$$S = Sprev + Eo * \frac{\exp(-CNcoef - Sprev)}{Smax} - Rday - Qsurf \ldots\ldots (2.6)$$

In which Sprev is the retention parameter for the previous day (mm), Eo is the potential evapotranspiration for the day (mm/day), CNcoef is the weighting coefficient used to calculate the retention coefficient for daily curve number calculations dependent on plant evapotranspiration, Smax is the maximum value the retention parameter can achieve on a given day (mm), and Qsurf is the surface runoff (mm).

The initial value of the retention parameter is defined as

$$S=0.9*Smax\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.7)$$

The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. SCS defines three antecedent moisture conditions:

i-dry (wilting point),

ii-average moisture, and

iii-wet (field capacity).

The moisture condition I curve number is the lowest value the daily curve number can assume in dry condition. The curve number for moisture condition I and III are calculated with equations 2.8 and 2.9.

$$CN1 = CN2 - \frac{20(100 - CN2)}{100 - CN2 + \exp\big(2.533 - 0.0636(100 - CN2)\big)} \ldots\ldots\ldots (2.8)$$

$$CN3 = CN2 * \exp(0.00673(100 - CN2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.9)$$

Typical curve number for moisture condition II are listed in various tables (Neitsch et., 2005). The values are appropriate for a 5% slope. Williams (1995) developed an equation to adjust the curve number to a different slope:

$$CN2S = \frac{CN3 - CN2}{3} * (1 - 2 * \exp(-13.86. slp)) + CN \ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

In which, CN1 is the moisture condition I curve number,

CN2 is the moisture condition II curve number for the default 5% slope,

CN3 is the moisture condition III curve number for the default 5% slope,

CN2S is the moisture condition II curve number adjusted for slope and

Slp is the average percent slope of the sub basin

SWAT calculates the peak runoff rate with a modified rational method. There are many methods that are developed to estimate potential evapotranspiration (PET). Three method are incorporated in to SWAT:

- The penman-Monteith method (Monteitch, 1965)
- The Priestley-Taylor method (Priestley and Taylor, 1972) and
- The Hargreaves method (Hargreaves et al., 1985)

These methods have various data needs of climate variables. Penman- Monteith method requires solar radiation, air temperature, relative humidity and wind speed, Priestley-Taylor method requires solar radiation, air temperature and relative humidity and Hargreaves method requires air temperature only. Based on the available data in the catchment the Penman-Monteith method was selected.

### 2.6.2 Sediment component

Erosion is the wearing down of a landscape over time. It includes the detachment, transport, and deposition of soil particles by the erosive forces of raindrops and surface flow of water (Dereje, 2010). SWAT computes erosion for each HRU caused by rainfall and runoff with the Modified Universal Soil Loss Equation (MUSLE). The modified universal soil loss equation (Williams, 1975) is given by equation 2.11

$$Sed = 118 * (Q_{Surf} * q_{peak} * A_{hru})^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \ldots\ldots (2.11)$$

Where Sed is the sediment yield on a given day in metric tons, $Q_{surf}$ is the surface runoff from the watershed in mm/ha, $q_{peak}$ is the peak runoff rate in cubic meter per second, $A_{hru}$ is the area of HRU, $K_{USLE}$ is the USLE soil erodability factor, $C_{USLE}$ is the USLE land cover and management factor, $P_{USLE}$ is the USLE support practice factor, $LS_{USLE}$ is the USLE topographic factor, and CFRG is the coarse fragment factor. In SWAT water is routed through the channels network using either the variable storage routing or Muskingum River routing method.

**Soil Erodibility Factor**

Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself.

(Wischmeier & Smith, 1978), define the soil erodibility factor as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. A unit plot is 22.1m (72.6-ft) long, with a uniform length-wise slope of 9%, in continuous fallow, tilled up and down the slope. Continuous fallow is defined as land that has been tilled and kept free of vegetation for more than 2 years. As noted that a soil type usually becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or clay fraction.

**Cover and Management Factor**

The USLE cover and management factor, $C_{USLE}$, is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow. (Wischmeier & Smith, 1978) The plant canopy affects erosion by reducing the effective rainfall energy of intercepted raindrops. Water drops falling from the canopy may regain appreciable velocity but it will be less than the terminal velocity of free-falling raindrops. The average fall height of drops from the canopy and the density of the canopy will determine the reduction in rainfall energy expended at the soil surface.

**Support Practice Factor**

The support practice factor, $P_{USLE}$, is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. Support practices include contour tillage, strip-cropping on the contour, and terrace systems. Stabilized waterways for the disposal of excess rainfall are a necessary part of each of these practices. Contour tillage and planting provides almost complete protection against erosion from storms of low to moderate intensity, but little or no protection against occasional severe storms that cause extensive break over of contoured rows. Contouring is most effective on slopes of 3 to 8 percent.

**Topographic Factor**

The topographic factor, $LS_{USLE}$, is the expected ratio of soil loss per unit area from a field slope to that from a 22.1-m length of uniform 9 percent slope under otherwise identical conditions.

**Coarse fragment factor**

The coarse fragment factor is calculated:

CRFG = exp(-0.053.rock). Where: rock is the percent rock in the first soil layer (%)

The conservation practice factor and cover & management factor for universal soil loss equation (USLE) are presented in Table (2.1, 2.2, and 2.3) for some conservation practices.

Table 2.1 P factor values and slope-length limits for contouring

| Land slope (%) | $P_{USLE}$ | Maximum length (m) |
|---|---|---|
| 1 to 2 | 0.6 | 122 |
| 3 to 5 | 0.5 | 91 |
| 6 to 8 | 0.5 | 61 |
| 9 to 12 | 0.6 | 37 |
| 13 to 16 | 0.7 | 24 |
| 17 to 20 | 0.8 | 18 |
| 21 to 25 | 0.9 | 15 |

Source (Wischmeier & Smith, 1978)

Table 2.2 Support practice factor (p-values) defined for Ethiopian

| Parameter Description | P-value |
|---|---|
| Contour ploughing | 0.9 |
| Ploughing up and down slope | 1 |
| Appling mulch | 0.6 |
| strip cropping | 0.8 |
| Terraces | 0.6 |
| Protected area | 0.5 |

The parameters, which were defined for Ethiopia by (Hurni, 1985)

Table 2.3 Support practice (C-values) defined for Ethiopia

| Parameter Description | C-value |
|---|---|
| Cover or management factor (USLE_C) (Teff) | 0.25 |
| Cover or management factor (USLE_C) (barley and wheat) | 0.15 |
| cover or management factor (USLE_C) (Maize and Sorghum ) | 0.1 |
| cover or management factor (USLE_C) (bush or shrub ) | 0.02 |
| Cover (USLE_C factor) (forest ) | 0.003 |
| Cover or management factor(USLE_C) (dense grass ) | 0.01 |
| Cover or management factor(USLE_C) (degraded grass ) | 0.05 |

The parameters, which were defined for Ethiopia by (Hurni, 1985)

### 2.6.3 Sediment transport

Sediment transport in the channel network is a function of two processes, deposition and degradation; SWAT compute both of them by using the same channel dimensions for the entire simulation. The amount of sediment degradation in the channel can be calculated by the model by using equation 2.12 and the net amount of sediment deposited in the reach segment is calculated by equation 2.13.

$$Sed_{\deg} = (Conc_{sed,ch,mx} - Conc_{sed,ch,i}) * V_{ch} * K_{ch} * C_{ch} \quad \text{.............................................} \quad (2.12)$$

$$Sed_{dep} = (Conc_{sed,ch,i} - Concmx) * V_{ch} \quad \text{....................................................................} \quad (2.13)$$

Where: $Sed_{deg}$ is the amount of sediment re-entrained in the reach segment (metric tons), $Conc_{sed,ch,i}$ is the amount of initial sediment concentration in the reach (kg/l or ton/m3), $Conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m3), $K_{ch}$ is the channel erodibility factor (cm/hr/pa), $C_{ch}$ is the channel cover factor and $V_{ch}$ is the volume of water in the reach segment ($m^3$), $sed_{dep}$ is the amount of sediment deposited in the reach (metric tons).

Once the amount of degradation and deposition has been calculated by the above equations 2.12 and 2.13 respectively), then the final amount of sediment in the reach is determined by equation 2.14 and the amount of sediment transported out of the reach is calculated by equation 2.15 by the model.

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{\deg} \quad \text{...............................................} \quad (2.14)$$

$$Sed_{out} = Sed_{ch} * \frac{V_{out}}{V} \quad \text{.........................................................................} \quad (2.15)$$

Where $sed_{ch}$ is the amount of suspended sediment in the reach (metric tons), $Sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period(metric tons), $Sed_{deg}$ is the amount of sediment re-entrained in the reach segment (metric tons), $Sed_{out}$ is the amount of sediment transported out of the reach (metric tons), $Sed_{ch}$ is the amount of suspended sediment in the reach (metric tons), $V_{out}$ is the volume of outflow during the time step ($m^3$) and $V_{ch}$ is the volume of water in the reach segment ($m^3$).

### 2.6.4 Surface Runoff and Sediment lag

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated and also Sediment in the surface runoff is lagged as well. SWAT incorporates a surface runoff storage feature to lag part of the surface runoff release to the main channel. Once surface runoff is calculated, the amount of surface runoff released to the main channel is calculated by equation 2.16 and after the sediment load in surface runoff is calculated, the amount of sediment released to the main channel is calculated using equation 2.17 by the model.

$$Q_{surf} = (Q'_{surf} + Q_{stor,i-1})(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]) \quad (2.16)$$

$$Sed = (Sed' + Sed_{stor,i-1})(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]) \quad (2.17)$$

Where: $Q_{surf}$ is amount of surface runoff discharged to main channel in a day (mm), Q' is amount of surface runoff generated in a sub basin in a day (mm), $Q_{stor,\ i-1}$ is the surface runoff stored or lagged from the previous day (mm), Surlag is the surface runoff lag coefficient, $t_{conc}$ is the time of concentration for the sub basin (hrs) and in equation 13 Sed is the amount of sediment discharged to the main channel on a given day (metric tons), Sed' is the amount of sediment load generated in the HRU on a given day (metric tons), $Sed_{stor,\ i-1}$ is sediment stored or lagged from the previous day (metric tons)

### 2.6.5 Sediment in lateral and ground water flow

Even though, it is small in proportion to the surface flow contribution, SWAT allows the lateral and groundwater flow to contribute sediment to the main channel and calculated:

$$Sed_{lat} = \frac{(Q_{lat} + Q) * Area_{HRU} * Conc_{sed}}{1000} \quad (2.18)$$

Where $sed_{lat}$ is the sediment loading in lateral and ground water flow (metric tons), $Q_{lat}$ is the lateral flow for a given day (mm water), $Q_{gw}$ is the groundwater flow for a given day (mm water), Area HRU is the area of the HRU ($km^2$) and $Conc_{sed}$ is the concentration of sediment in lateral and groundwater flow (mg/l).

### 2.6.6 Routing phase of the hydrologic cycle

The second phase of the SWAT hydrologic simulation, the routing phase, consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network. The change in channel dimensions with time due to down cutting and widening is also included. Similar to the case for the overland flow, the rate and velocity of flow is calculated by using the Manning's equation. The main channels or reaches are assumed to have a trapezoidal shape by the model. Two options are available to route the flow in the channel networks: the variable storage and Muskingum methods. Both are variations of the kinematic wave model. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model. In the latter method, when a flood wave advances into a reach segment, inflow exceeds outflow and a wedge of storage is produced. As the flood wave retreat, outflow exceeds inflow in the reach segment and a negative wedge is produced. In addition to the wedge storage, the reach segment contains a prism of storage formed by a volume of constant cross-section along the reach length (Asmamaw, 2013).

For this study, the variable storage method was adopted. The method was developed by (Williams, 1975) and recommended (Arnold et al, 1995). The Storage routing is based on the continuity equation:

$$\Delta V_{stored} = V_{in} - V_{out} \quad \text{.........................................................................} \ (2.19)$$

Where: $V_{in}$ is volume of inflow during the time step (m3), $V_{out}$ is volume of outflow during the time step ($m^3$), and $\Delta V_{stored}$ is change in volume of storage during the time step ($m^3$). The above equation 2.19 can also be rewritten in detailed as follows:

$$V_{stored,2} - V_{srored,1} = \Delta t\left(\frac{q_{in,1} + q_{in,2}}{2}\right) - \Delta t * \left(\frac{q_{out,1} + q_{out,2}}{2}\right) \quad \text{.....................} \ (2.20)$$

Where: $\Delta t$ is the length of the time step (s), $q_{in,1}$ is the inflow rate at the beginning of the time step ($m^3/s$), $q_{in,2}$ is the inflow rate at the end of the time step ($m^3/s$), $q_{out,1}$ is the outflow rate at the beginning of the time step ($m^3/s$), $q_{out,2}$ is the outflow rate at the end of the time step ($m^3/s$), $V_{stored,1}$ is the storage volume at the beginning of the time step ($m^3$) and $V_{stored,2}$ is the storage volume at the end of the time step ($m^3$).

### 2.6.7 Model Efficiency Evaluation

The performance of SWAT is evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination ($R^2$), Percent bias (PBIAS) and Nash-Sutcliffe simulation efficiency (ENS) are the goodness of fit measures used to evaluate model prediction.

**The Coefficient of determination ($R^2$):** value is an indicator of strength of relationship between the observed and simulated values. It indicates how well the dispersion of the measured data is predicted by the model. Its value ranges between 0 and 1, with the zero being no correlation at all and the value of one indicates perfect match, and computed by equation 2.21.

$$R^2 = \left[ \frac{\sum_{i=0}^{n} \left[ \left( Q_{sim} - \bar{Q}_{sim} \right) \left( Q_{obs} - \bar{Q}_{obs} \right) \right]^2}{\sum_{i=0}^{n} \left[ \left( Q_{obs} - \bar{Q}_{obs} \right)^2 \sum_{i=0}^{n} \left( Q_{sim} - \bar{Q}_{\sin} \right)^2 \right]} \right] \text{.............................. (2.21)}$$

**The Nash-Sutcliffe simulation efficiency (ENS)**: indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, ENS is 1. If the ENS is between 0 and 1, it indicates deviations between measured and predicted values. If ENS is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash & Sutcliffe, 1970). This coefficient is calculated by equation 2.22 given below.

$$NSE = 1 - \left[ \frac{\sum_{i=0}^{n} \left( Q_{obs} - Q_{sim} \right)^2}{\sum_{i=o}^{n} \left( Q_{obs} - \bar{Q}_{obs} \right)^2} \right] \text{............................ (2.22)}$$

**Percent bias (PBIAS):** measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al, 1999) and calculated by equation 2.23

$$PBIAS = \frac{\sum_{i=0}^{n}(Q_{obs} - Q_{sim})}{\sum_{i=0}^{n}(Q_{obs})} * 100 \text{ ..........................} (2.23)$$

Where: n is the number of observations during the simulation period, $Q_{obs}$ is the Observed flow data; $Q_{sim}$ is the simulated flow value with the respected time; $\bar{Q}_{obs}$ and $\bar{Q}_{sim}$ are the arithmetic means of the observed and simulated values.

**Root mean Square error observation standard deviation Ratio (RSR):** it is an error index indicator. RSR ranges from 0 to 1 with the lower value closer to zero indicating higher accuracy of the model performance. Values approaching 1 indicate a poor model performance.

$$RSR = \frac{RMSE}{STDev} = \frac{\sqrt{\sum_{i=1}^{n}(oi - si)2}}{\sqrt{\sum_{i=1}^{n}(oi - si)2}} \text{ ..............................} (2.24)$$

## CHAPTER THREE

# 3 MATERIALS AND METHODS

## 3.1 Description of the study area

Upper Awash basin has an area of 10,553.84 $km^2$. The basin is characterized mainly by agricultural land, forest and in limited parts by urban area, wetland and pastures. Agricultural land coverage is about 62.27 %, Shrubland 10.48%, perennial crop 9.57% ,Natural forest 5.99% Grassland 5.27%,and Urban land is 3.67 % respectively. Chromic Vertisols are the dominant soil types in the area which cover 50.14 % of the basin. Calcic fluvisols, Chromic Cambisols, Eutric Nitosols Calcic Xerosols, Vertic Cambisols are also the most common types. The average basin slope ranges from 0.7 % to 16.5 %. The study area has an elevation range of 1584m a.s.l to 3576m a.s.l.

The hydro-climatology of the basin is variable both seasonally and annually. Months from May to September are the monsoon season which contributes to the occurrence of high run off. As a result, the peak stream flows in rivers are observed during these periods, while for the remaining months of the year, flows in the perennial rivers are contributed by base flow during dry period. From 1990 to 2014 at Hombole gauging station, the average maximum and the average minimum discharge was observed to be 235.5$m^3$/s in August and 3.76$m^3$/s in January respectively. Similarly, maximum rainfall was observed in month of July. The observed maximum intensity was 60mm/hr.

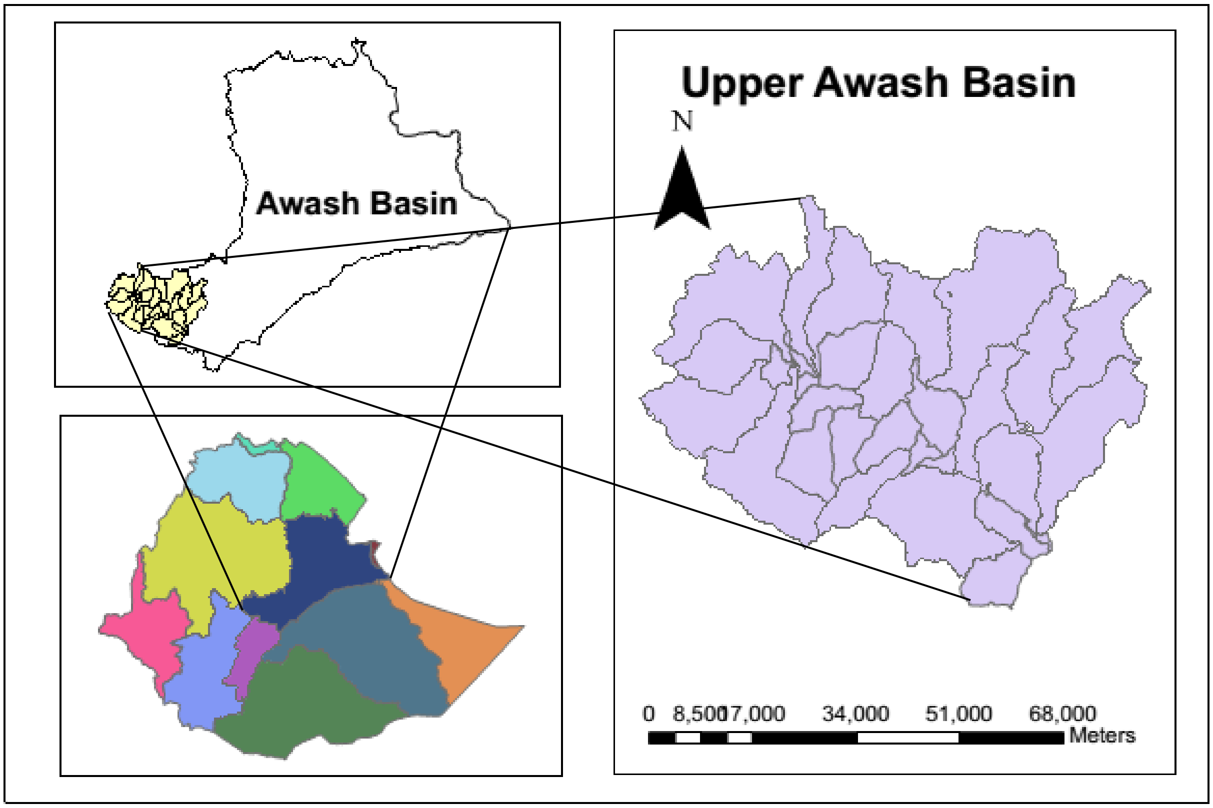



Figure 3.1. Location of Upper awash basin

The Awash River rises in the central highlands at an altitude of 3000m to the west of Addis Ababa after flowing through Koka reservoir, it flows north-east wards along the rift valley until eventually discharges in to Lake Abe. The Awash basin has a total area of 110,000km$^2$. The basin is divided in two; Western catchment of 64,000km$^2$ and eastern catchment 46,000km$^2$ with only western catchment contributing to the main river flow. The eastern catchment drains to desert area. The erosion rates in the Awash basin as a whole and in Koka reservoir catchment in particular is high with values generally exceeding 6,000t/km$^2$/y as high as 15,000 to 20,000 ton/km$^2$/y. The high rate of erosion in the catchment area is mainly due to negative impact of human activities and gully erosion.

The climate of Awash basin is characterized by the Inter-Tropical convergence zone (ICTZ) and the seasonal rainfall distribution with in the basin results from the annual migration of the ICTZ. In March, the ICTZ advances across the basin from the south, bringing the small rains. In June and July, it reaches it's most northerly location beyond basin which then experiences heavy rains. The ICTZ returns south wards during August to October, restoring the drier easterly air stream which prevails until the cycle the cycle repeat in March (DH WoWR. 1985). The mean annual temperature at Koka reservoir is 22.8°c with a maximum of 27.8°c in June. The mean annual wind speed at Koka is 1.2m/s, with the windiest month being June and July with the mean monthly values of 1.9 and 1.6m/s respectively. The weather system that cause rainfall over the study area are Sub Tropical Jet (STJ), Inter Tropical Convergence Zone (RSCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and the Somalia Jet (SJ). The area is dominated by bimodal rainfall type. According to the National Metreological Agency, the study area is characterized by quasi-double maxima rainfall pattern, with a small pick in April and maximum pick in August. The rainfalls in the high lands show a strong correlation with altitude (Lemma, 1996).

The southern section of the basin including the catchment of Koka reservoir has a more prolonged exposure to the moist air streams. Due to the orographic effect,the rainfall increases from East to West and the Mean Annual Rainfall (MaR) of the catchment area is 1012mm

Two major geological formations can be found in the area of the Awash basin: the highlands of the Ethiopian plateau and the lowlands of the rift valley. The uplifting of the plateau during the cretaceous period at the end of Mesozoic Era (about 70 million years ago) was followed by a series of parallel normal faults as a result of the diverging tectonic platform of Somalia and Afar in the Tertiary period of the Cenozoic Era (about 30 to 25 million years ago). (Ethiopian Geological Survey Enterprise 1981). The bed rock and soils in the area are important for the amount and composition of transported sediments in the river. The geology of the reservoir area carried out before the dam construction indicates that the area intended for water storage (reservoir area) was alluvial plain, through which the river runs in meanders. The deposits consist of clay, some zones of sand and tuff (Nor Consults, 1997).

Farmers extensively cultivate the upper awash basin upstream of Koka reservoir. The upper most part, rich of rainfall, is mainly used for crop production like Barley and Teff. Acacia and eucalyptus trees are prevailing ones, but due to the growing demand of fuel wood they are cleared time to time by the local users. The effect of land use on sediment yield can be clearly seen by comparing the runoff and sediment yield in the rivers. Land use in the area is mainly dominated by moderately to intensively cultivated subsistence base cropland, grazing land, settlement and some parts of the highland area are covered by eucalyptus trees, shrubs and grass. A serious problem occurs because of the very rigorous way of using soil as a natural resource (Halcrow, 1989).

## 3.2 Description of Koka Dam

The Koka dam with the objective of generating hydropower was commissioned in 1960. The original storage capacity of the reservoir at full Supply level of 1590.7m.a.s.l. or 110.3m reduced level, was 1650Mm$^3$.

The dam was constructed on the Awash River. The Awash River originates from the highlands and is characterized by high peak flash floods, which carry lots of sediment. It can thus be anticipated that the water storage of the reservoir is subject to sever problem of siltation. Three sedimentation surveys have been carried out on the reservoir previously. From these surveys, it was concluded that the average rate of sedimentation in the reservoir is in the order of 25Mm$^3$ per annum (Halcrow, 1989).

**DAM**

Type……………………………………………………Concrete Gravity Dam

Crest Elevation…………………………………………1593.20m (a.s.l)

Crest length……………………………………………458m

Maximum height………..................................................23.8m

Maximum spillway discharge at 1590.70m…………….1000 m$^3$/s

**RESERVOIR**

Maximum level……………………………………….....1590.70m (a.s.l)

Minimum level………………………………………......1580.70m (a.s.l)

Total storage capacity at 1590.70m………………………1,850 × 10$^6$m$^3$

Useable storage capacity…………………………………1, 680 × 10$^6$m$^3$

Reservoir area at 1590.70m………………………………236km$^2$

Regulated flow……………………………………………42.3m$^3$/s

**SURGE TANK**

Diameter………………………………………………….18m

Height…………………………………………………..20m

**PENSTOCKS**

Number…………………………………………………3

Diameter………………………………………………..3.5m

Length…………………………………………………..50.7m/55.4m/61.1m

Figure 3.2 Koka Dam

## 3.3 Data collection

The necessary data that was collected and used for this study can be classified into spatial and time series data. Spatial data used are DEM, Land use/cover, and soil map of the study area were collected from Ministry of Water, Irrigation and Electricity. The time series data are Metreological and Hydrological data and these data were collected from Ethiopian National Metreological Agency and Ministry of Water, Irrigation and Electricity respectively.

### 3.3.1 Metreological Data

The metrological data required were: daily precipitation, daily maximum and daily minimum air temperature, daily solar radiation, daily wind speed, and daily relative humidity. If any of these data was not available, which is very likely, SWAT can generate data using weather generator. For this monthly statistical values are needed from daily data values were needed to be generated from daily ones.

- Precipitation: the daily precipitation and temperature of all gauging stations (Addisababa bole, Debre Zeyit, Ejere, Ejersa lele, Ginchi, Nazret and Wolliso) were prepared in dbf format.
- Temperature: the daily temperature of five gauging stations (Addisababa bole, Debre Zeyit, Nazret and Wolliso) were prepared in dbf format.
- Solar radiation: the solar radiation of three gauging stations (Addisababa bole, Debre Zeyit and Nazret) were prepared in dbf format.
- Relative humidity: the solar radiation of four gauging stations (Addisababa bole, Debre Zeyit, Nazret and Wolliso) were prepared in dbf format and
- Wind speed: the wind speed of four gauging stations (Addisababa bole, Debre Zeyit, Nazret and Wolliso) were prepared in dbf format. The selected principal stations were Addisababa bole and Debre Zeyit gauging station and these data for the rest of the stations were generated by SWAT. More over these data were required when Penman Montheith equation is used to evaluate potential evapotranspiration.
- Weather simulation data: these data consists of monthly average values of all the values required by the SWAT model in order to generate daily values.
- All the above data were collected from Ethiopian National metrological agency for the period from (1990-2013 G.C).

Table 3.1 Metrological Stations

| Station | XPR | YPR | Elevation |
|---|---|---|---|
| Addis ababa bole | 472523.9 | 998546.5 | 2354 |

| | | | |
|---|---|---|---|
| Addisalem | 432225.9 | 999552.9 | 2372 |
| Debrezeyt(AF) | 494500.3 | 965370.8 | 1900 |
| Ejere | 528246.7 | 969798.7 | 2254 |
| Ejeresa lelle | 465418.1 | 911197.7 | 1797 |
| Ginchi | 404738.4 | 996808.1 | 2132 |
| Nazret | 531179.9 | 945113.5 | 1622 |
| Wolliso | 388113.8 | 945249.6 | 2058 |

### 3.3.2 Hydrological Data

#### *3.3.2.1 Flow Data*

Daily flow data is required for SWAT simulated result calibration and validation. This data was obtained from Ministry of Water, Irrigation and Electricity, hydrological department from 1990-2013 G.C. Depending on the extent of calibration and validation, flow data was collected and arranged as per the requirement of SWAT model.

#### *3.3.2.2 Sediment Data*

There are sites, which has measured suspended sediment data in the upper awash river basin with a very short data. Depending on the observed suspended sediment data the remaining values were generated from sediment rating curve for sensitivity and calibration analysis.

Table 3.2 Flow station

| NAME | XPR | YPR |
|---|---|---|
| Mojo Upstream of Koka | 502201.6 | 931835.5 |
| Akaki | 475810.9 | 981592.5 |
| Awash Melka Kunturi | 455998.4 | 961708.5 |
| Awash Melka Hombole | 475779.1 | 926314.6 |
| Awash near Bello | 436222.7 | 978318.3 |

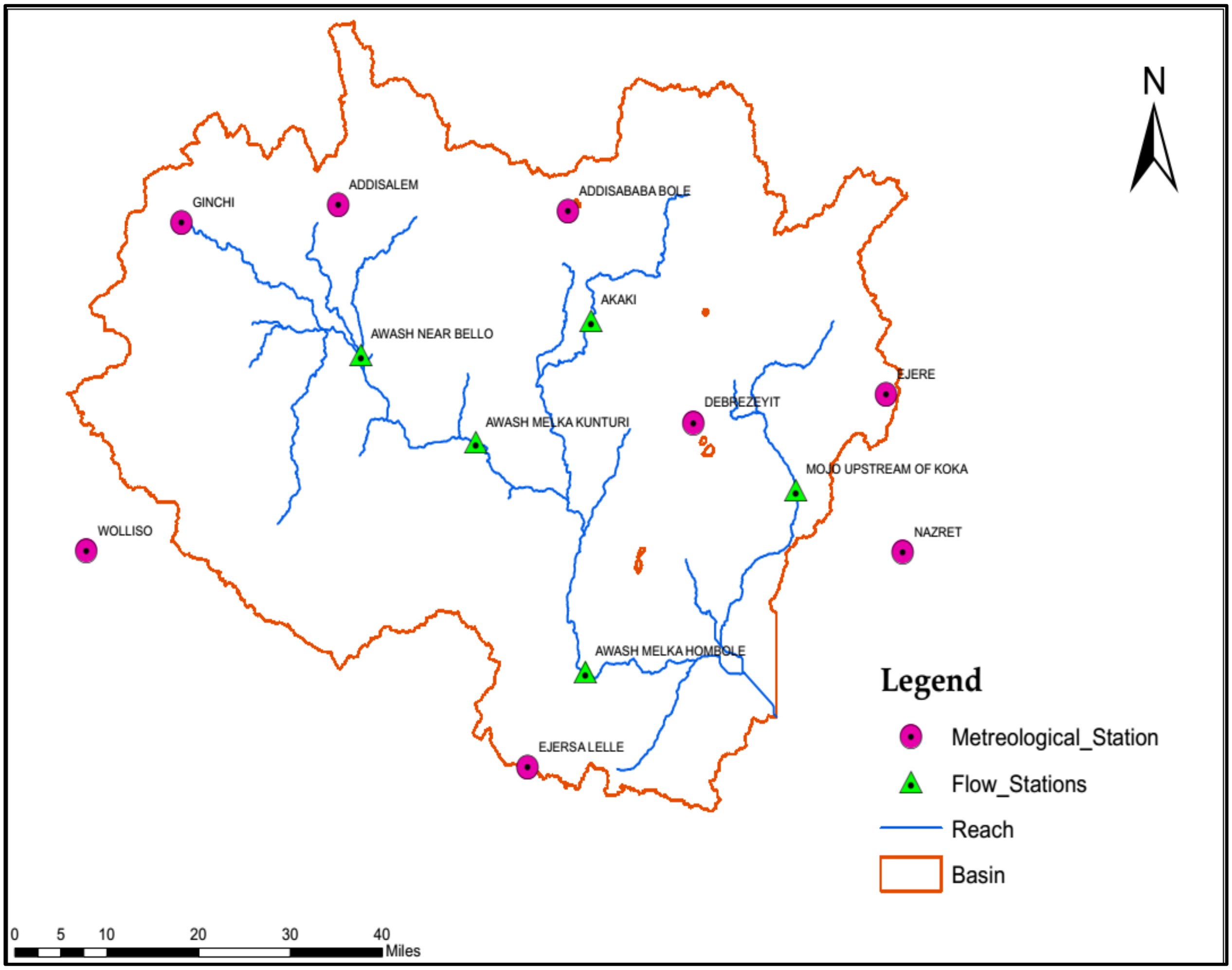



Figure 3.3 Flow and Metreological Station of Upper Awash Basin

### 3.3.3 Digital Elevation Model (DEM) Data

The digital elevation model (DEM) is any digital representation of a topographic surface and it is specifically made available in the form of raster or regular grid of spot heights. It is the basic input of SWAT hydrological model. The upper awash basin was delineated and River networks were generated from DEM. The DEM obtained for this study was obtained from Ministry of Water, Irrigation and Electricity and it has a resolution of 30m x 30m. Elevation of the study area ranges from 3576m amsl to 1584m amsl. Figure 3.2 shows elevation distribution of the Upper Awash watershed.

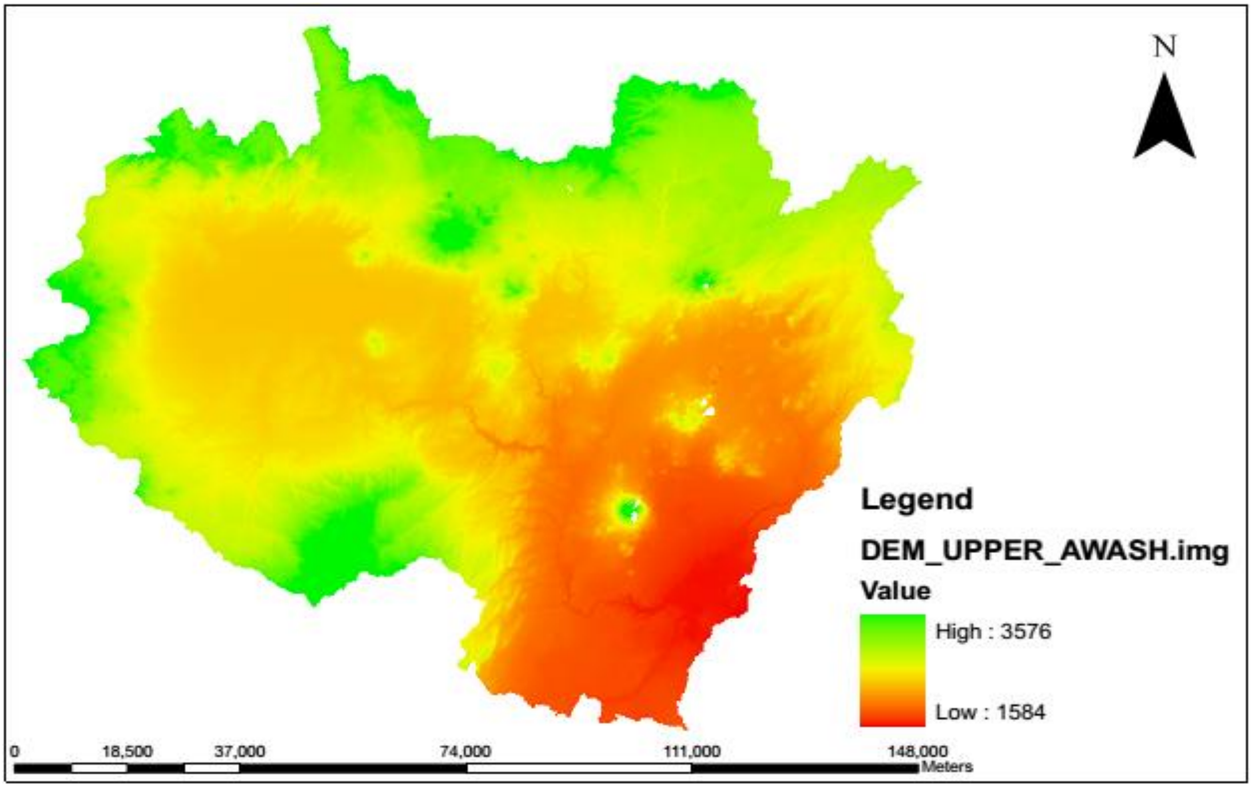



Figure 3.4 Digital Elevation Model of the basin

### 3.3.4 Soil Map Data

Soil physical and chemical properties are other input required by SWAT's soil data base. The physical property of the soil in each horizon governs the movement of water, air through the soil profile and has major impact on cycling of water in hydrological response unit (HRU) and is used to determine water budget for the soil profile, daily runoff and erosion. Properties like soil texture ( % clay, % sand, and % clay), organic content and bulk density were obtained from FAO database (FAO, 2002), whereas available water content, saturated hydraulic conductivity, permanent wilting point (PWP), field capacity (FC), maximum layer depth and number of layers were found by using the model called Soil-Plant-Atmosphere-Water field and pond hydrology (SPAW). The model needs % sand at the vertical space provided in the triangle, % clay at the horizontal space provided for it as input and gives the other required parameters as output.

It was observed that Chromic Vertisols and Calcic fluvisols are the most dominant soils in the basin. The value of different soil parameters (properties) for each soil, which were, collected from the above soil data sources are listed in Appendix. Figure 3.3 shows the distribution of different soil type in the basin and SPAW model window respectively.

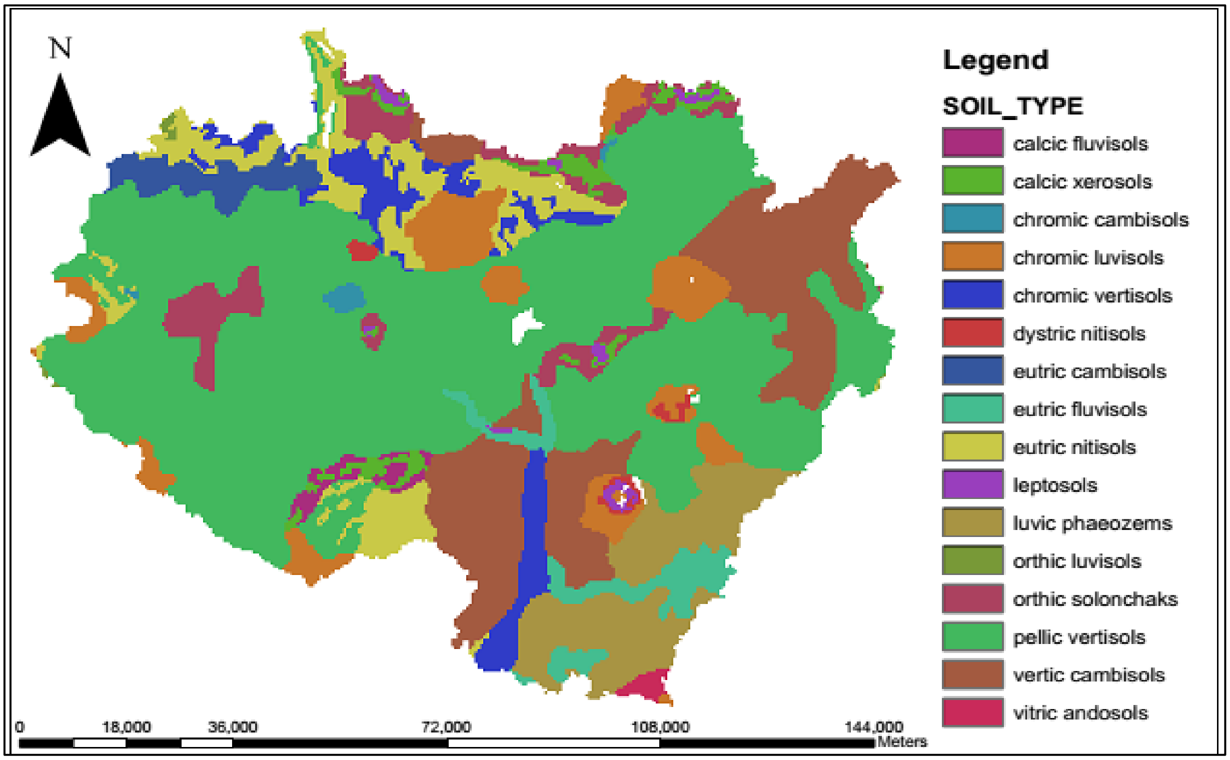



Figure 3.5. Soil map of the study area

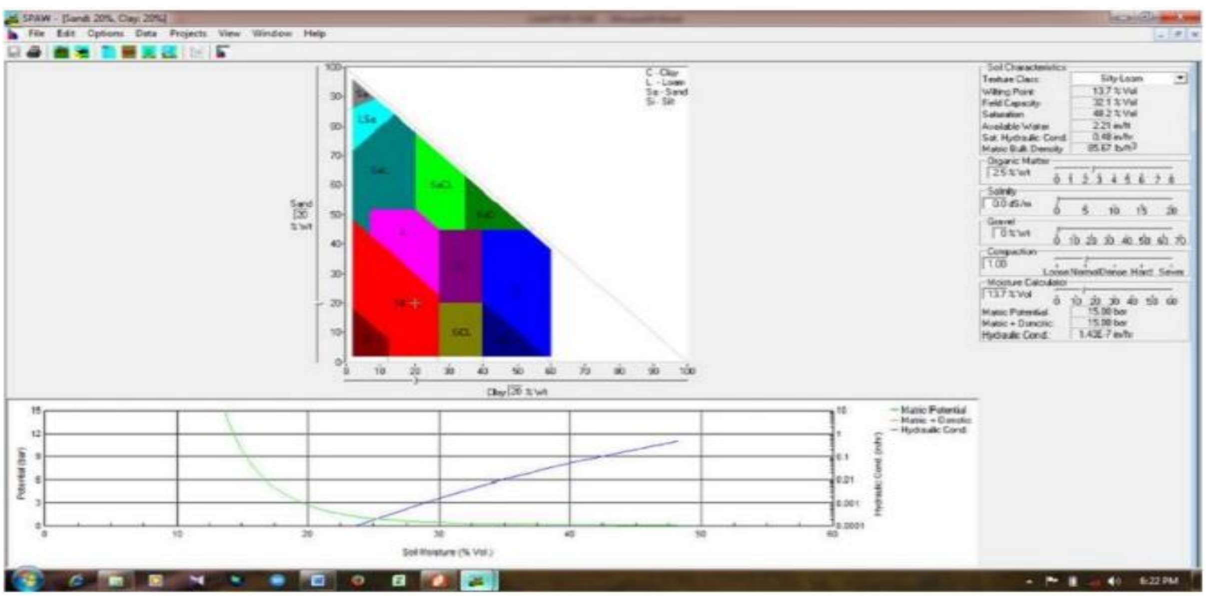


Figure 3.6. SPAW model

### 3.3.5 Land use /land Cover Map

Spatial distribution and specific land use parameters were required for modeling. SWAT has predefined land uses identified by four letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interface. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model. Hence the classified land use map and its attribute were adjusted to the SWAT model requirement format and database. Agricultural land use is the dominant land use in the Upper Awash basin.

Two land use data (1990 and 2013 G.C.) were obtained from Ministry of Agriculture and Ethiopian Mapping Agency in shape file and raster form respectively. Figure 3.7 and Figure 3.8 shows the 1990 and 2013 land use/land cover of the study area respectively while table three represent the land use distribution of the study area.

### 3.3.6 Software and Material used

Models and software used for land use dynamics on runoff and sediment yield in the study area was Arc GIS 9.3 extension of SWAT model that is Arc SWAT 2005.93.7b. Arc GIS 9.3. was used for input preparation of SWAT model, to extend the Arc SWAT model and to prepare the Thiessen polygon of the metrological stations in the watershed.

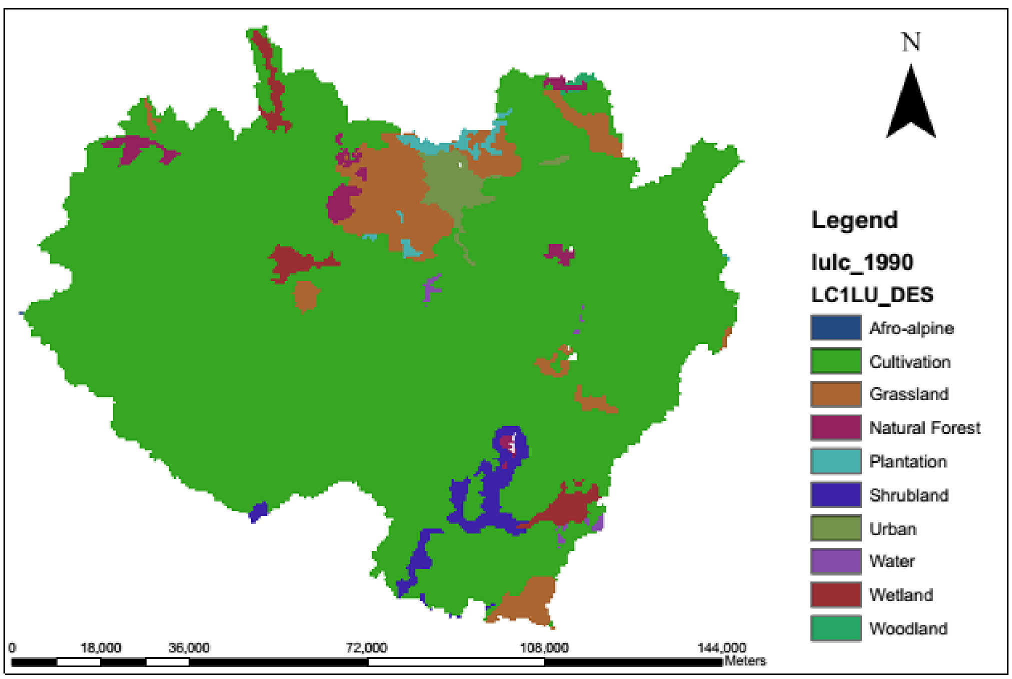



Figure 3.7. Land use/land cover map of the study area (1990)

Table 3.3 Land use distribution of the basin

| Sr.No_ | LANDUSE: | SWAT code | Area(Ha) | %Wat.Area |
|---|---|---|---|---|
| 1 | Cultivation | AGRC | 875,124.44 | 82.92 |
| 2 | Wetland | WETN | 13,148.05 | 1.25 |
| 3 | Woodland | FRSD | 900.47 | 0.09 |
| 4 | Natural Forest | FRST | 93,427.60 | 8.85 |
| 5 | Grassland | RNGE | 35,112.90 | 3.33 |
| 6 | Plantation | WETF | 6,691.01 | 0.63 |
| 7 | Urban | URBN | 14,543.79 | 1.38 |
| 8 | Water | WATR | 975.99 | 0.09 |
| 9 | Afro_Alphine | FRSE | 22.2 | 0.00 |
| 10 | Shrubland | RNGB | 15,437.58 | 1.46 |
|  | Total |  | **1,055,384.01** | **100.00** |

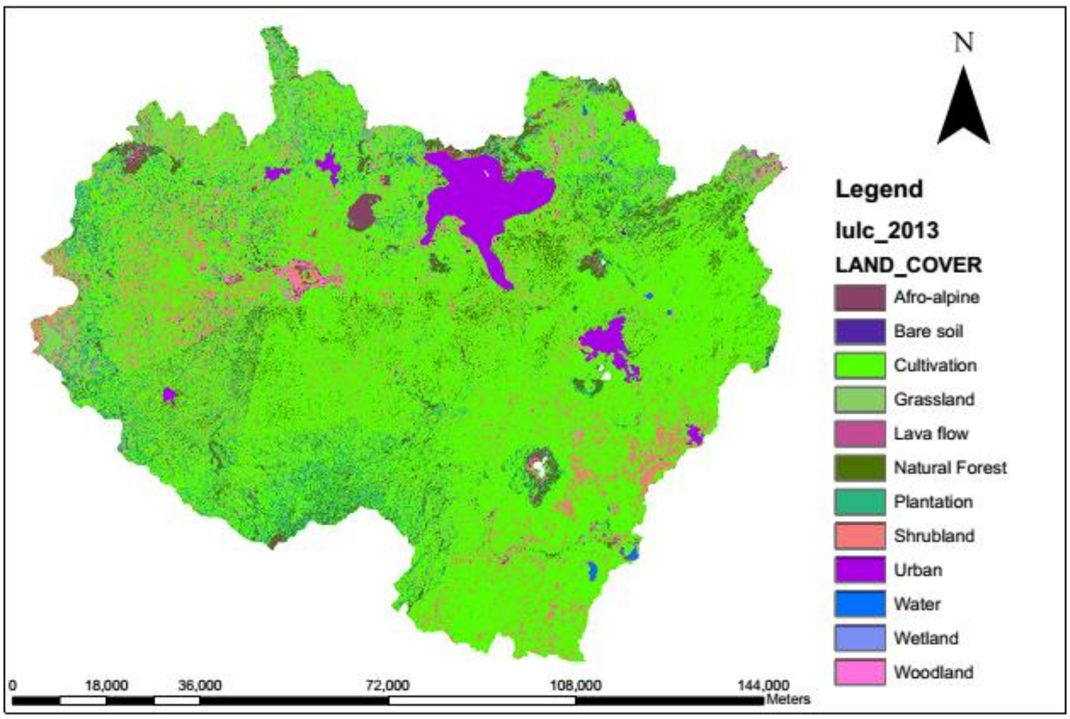



Figure 3.8. Land use/land cover map of the study area (2013)

Table 3.4 Land use distribution of the study area (2013)

| Sr.No_ | LANDUSE: | SWAT code | Area(Ha) | %Wat.Area |
|---|---|---|---|---|
| 1 | Cultivation | AGRC | 657,178.35 | 62.27 |
| 2 | Wetland | WETN | 560.91 | 0.05 |
| 3 | Woodland | FRSD | 15,478.65 | 1.47 |

| | | | | |
|---|---|---|---|---|
| 4 | Natural Forest | FRST | 63,210.30 | 5.99 |
| 5 | Grassland | RNGE | 55,596.58 | 5.27 |
| 6 | Plantation | WETF | 101,038.30 | 9.57 |
| 7 | Urban | URBN | 38,707.68 | 3.67 |
| 8 | Water | WATR | 1,129.05 | 0.11 |
| 9 | Afro_Alphine | FRSE | 10,363.98 | 0.98 |
| 10 | Shrubland | RNGB | 110,562.85 | 10.48 |
| 11 | Lava flow | PAST | 51.35 | 0.00 |
| 12 | Bare soil | SWRN | 1,506.01 | 0.14 |
| | Total | | **1,055,384.01** | **100.00** |

## 3.4 Data Analysis and Interpretation

Engineering studies of water resources development and management depend heavily on meteorological and hydrological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. To determine whether the data meet these criteria, we need a simple but efficient screening procedure. A time series of hydrological data is strictly stationary if its statistical properties (e.g. its mean, variance, and higher-order moments) are unaffected by the choice of time origin. (By 'unaffected', we mean that estimates of these properties agree within the range of expected statistical variability.) The basic data-screening procedure presented here is based upon split-record tests for stability of the variance and mean of such a time series.

### 3.4.1 Metreological data analysis

Daily precipitation, daily temperature (maximum and minimum), sunshine hours, relative humidity and wind speed were collected from meteorological stations within and around the basin. The seven stations, which are used for the model, were presented in Table 3.1 before which are within and around Upper Awash basin.

#### *3.4.1.1 Filling Missing Rainfall Data*

Measured precipitation data are important to many problems in hydrologic analysis and design.But, due to failure of the observer to make the necessary visit to the gage, Vandalism of recording gages or instrument failure (by mechanical or electrical malfunctioning) may result in missing data. There are methods to estimate these missing values in the given stations. For this study missing values were estimated from other stations around the missed record station by considering the assumptions of at least three as close to and evenly spaced around the station with the missing record station as possible. Simple Arithmetic mean method was used where the mean monthly rainfall of all the index stations is within 10% of the station under consideration (station x) and calculated the missing data by equation 3.1. Whereas the mean monthly rainfall of one or more of the adjacent (index) stations differs from that of station x by more than 10% then the normal ratio method was used (equation 3.2).

$$P_x = \frac{1}{N}(P_A + P_B + P_C \ldots\ldots + P_N) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

$$P_x = \frac{1}{N}\left(\frac{N_x}{N_A}P_A + \frac{N_x}{N_B}P_B + \frac{N_x}{N_C}P_c \ldots\ldots\ldots\ldots + \frac{N_x}{N_N}P_N\right) \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

Where $P_X$ is the precipitation for the station with missed record, $P_A$, $P_B$, $P_C \ldots P_N$ are the corresponding precipitation at the index stations and $N_A$, $N_B$, $N_C$, $N_N$ and $N_X$ are the long term mean monthly precipitation at the index stations and at station x under consideration respectively.

**Areal Rainfall computation**

Rain gauges represent point sampling of the areal distribution of a storm. In practice, hydrological analysis requires knowledge of the rainfall over an area. Arithmetic mean, Thiessen polygon, Isohyetal methods are some of the methods used to convert point (gauged) rainfall values at various stations into an average value over a catchment. However, Thiessen polygon is used for this study due to its simplicity and the average rainfall over the catchment is calculated by:

$$P_{av} = \frac{P_1A_1 + P_2A_2 + P_3A_3 + \ldots\ldots\ldots + P_nA_n}{A_1 + A_1 + A_1 + \ldots\ldots + A_n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Where $p_{av}$ average areal rainfall (mm), $P_1$, $P_2$, $P_3 \ldots P_n$ precipitation of station 1,2,3…n, respectively and $A_1$,$A_2$, $A_3 \ldots A_n$ is area coverage of station 1,2,3…n respectively in the Thiessen polygon

### *3.4.1.2 Checking Homogeneity of Selected Rainfall station*

One of the methods to check homogeneity of the selected stations in the watershed is the non- dimensional rainfall records and plotted to compare the stations with each other. Non-dimensional values of the monthly precipitation of each station can be computed by:

$$P_i = \frac{p_{i,av}}{p_{av}} * 100 \quad \text{.......................................................} (3.4)$$

Where $P_i$ is non-dimensional value of precipitation for the month in station i. $P_{i,av}$ over years averaged monthly precipitation for the station i and $P_{av}$ is over year's averaged yearly precipitation of the station i.

#### *3.4.1.3 Checking Consistency and Adjustment of rainfall stations*

A consistent record is the one where the characteristics of the record have not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value. The consistency of rainfall records on selected stations commonly checked by double mass curve analysis. Double mass curve is a graphical method for identifying and adjusting inconsistency in a station record by comparing its time trend with those of adjacent stations. If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency can be differentiated from the time the significant change took place. If significant change in the regime of the curve is observed, it should be corrected by using equation 3.5. The stations used in this study have not undergone a significant change during the base line period (1990-2013) of the study.

$$P_{cx} = P_x * \frac{M_c}{M_a} \quad \text{.......................................................} (3.5)$$

Where: $P_{cx}$ is corrected precipitation at any time period, $P_x$ is original recorded precipitation at time period, $M_c$ is corrected slope of the double mass curve and $M_a$ is original slope of the double mass curve.

### 3.4.2 Hydrological data analysis

#### *3.4.2.1 Filling of Missing stream flow*

Unlike rainfall, stream flow shows strong serial correlation; the value on one day is closely related to the value on the previous and following days especially during periods of low flow or recession. Flow in the Awash River depends on the rainy season which occurs in June to September and also light rains are experienced in other seasons and it have good stream flow records with a small number of missing data in the study base line (1990-2013).

The infilling of the missing data was made into two divisions; for wet season missing data filled by using linear regression between consecutive wet season months; and for the dry season the recession curve method was used to fill the gaps by using equation 3.6

$$Q_t = Q_{t_o} \exp\left(-\frac{t-t_o}{K}\right) \text{.............................................} (3.6)$$

Where: $Q_t$ is the missed flow data (m3/s) in day, $Q_{to}$ is a specified initial daily mean discharge

(m3/s), k is the watershed characteristics and it is the inverse of flow recession (α) or also called a reaction factor.

K value can be calculated by the slope of the logarithmically transformed flow series data values of the flow last before the gap at time $t_0$ ($Q_{to}$) and the first flow value after the gap at time $t_1$ ($Q_{t1}$) as follow:

$$\frac{1}{k} = \alpha = \frac{\ln Q_{t_o} - \ln Q_{t_1}}{t_1 - t_o} \text{......................................} (3.7)$$

*4.2.2.2. Sediment rating curve preparation*

Sediment measurement in Awash River was taken by Ministry of Water, Irrigation and Electricity at gauge station was not in continuous time step; so that by using stream flow and measured sediment data can generate sediment load data in continuous time step, the relationship known as sediment rating curve.

The sediment rating curve is a relationship between the river discharge and sediment concentration or load (Clarke, 1994). It is widely used to estimate the sediment load being transported by a river. Generally, a sediment rating curve may be plotted showing average sediment concentration or load as a function of discharge averaged over daily, monthly or other time periods. So that using rating curve, the records of discharges are transformed into records of sediment concentration or load and the general relationship can be written as:

$$S = aQ^b \text{.......................................................} (3.9)$$

Where: S is sediment load in ton/day, Q is the discharge in $m^3/s$ and, a and b regression constants.

Hence, the measured value that was collected from the Ministry of Water, Irrigation and Electricity, hydrology and Water Quality Directorate was sediment concentration; so that the first work was to convert this value into sediment load by the following formula:

$$S = 0.0864 * Q * C \quad \text{.............................................} (3.10)$$

Where: S is sediment load in (ton/day), Q is flow of the stream (m3/s), C is sediment concentration (mg/l) and 0.00864 is conversion factor.

After calculated the sediment load the next step was making the relation between the continuous (daily time step) measured flow in $m^3/s$ and the measured sediment load (ton/day).

### 3.4.3 Model input, Set up, Calibration and Validation

#### *3.4.3.1 SWAT Model input*

Inputs including basin area and main channel length were determined by AVSWAT (ArcView GIS interface for SWAT) from DEM of the study area. SCS curve number and overland Manning's n values were chosen based on suggested parameters by the SWAT interface from soil and land use characteristics.

An ArcView GIS interface (AVSWAT) is available to generate model inputs from GIS data (DiLuzio et al. 2001). AVSWAT processes mapped land use and soils data as well as a Digital Elevation Model (DEM) to create a set of default model input files.

SWAT requires specific statistics about watershed characteristics such as topography, land use and land cover, soil types, weather data and management practices. The model uses a two-level taste schemes; first basin and sub-basin delineation is performed based on topographic information, followed by further crumbling into HRUs using land use and soil type consideration in order to represent heterogeneous watershed properties. Climate inputs are required since they control water balance that drives all the processes simulated in the watershed. Management practice of a watershed is needed because it greatly influences the sediment transported from basins.

The spatially distributed data (GIS input) needed for the AVSWATX interface include the Digital Elevation Model (DEM), soil data, land use and stream network layers. Data on weather and river discharge were also used for prediction of stream flow and calibration purposes

**A, Digital Elevation Model (DEM)**

Topography is defined by a DEM that describe the elevation of any point in a given area at a specific spatial resolution. A 30 m by 30 m resolution DEM was taken from the Ministry of Water, Irrigation and Electricity. The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Sub basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

**B, Soil Data**

SWAT model requires different soil textural and physio-chemical properties like soil texture (% clay, % sand, and % clay), organic content and bulk density were obtained from FAO database (FAO, 2002). Whereas available water content, saturated hydraulic conductivity, permanent wilting point (PWP), field capacity (FC), maximum layer depth and number of layers were found by using the model called Soil-Plant-Atmosphere-Water field and pond hydrology (SPAW).. Major soil types in the watershed are Chromic vertisols and Calcic fluvisols. The value of different soil parameters (properties) for each soil are listed in Appendix

**C, Land Use**

Land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. The land use map of the study area was obtained from Ministry of Agriculture and Ethiopian Mapping Agency for 1990 and 2013 G.C respectively. Both soil and land use land cover data can be in shape file or grid format.

**D, Weather Generator**

Weather data are amongst the indispensable inputs for SWAT model. Accordingly weather data’s such as daily data’s of rainfall, temperature (minimum and maximum), Wind Speed, Relative humidity and solar radiation were analyzed and prepared according to the model requirement (in dbf format).

There exists lack of full and realistic long period of metreological data in our country, which can be solved by the aid of Weather generator that solves the problem by generating data from the existing observed data. The weather generator requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years. To generate the data, weather parameters values were developed by using WGN maker (Excel Macro Solver) and dew point temperature calculator DEW02 were used.

The weather generator parameters from the stations of: Addis Ababa bole, and Debrezeyit are first loaded to the user weather generator database and the batch file containing the location and elevation of weather gauge stations are loaded sequentially. The missing Values in the existing data sets were filled with no dataset identifier (-99) and generated by the Program embedded in the model.

**E, Discharge and Sediment Yield Data**

Daily flow data and sediment concentration for Upper Awash basin (Mojo Upstream of Koka dam, Akaki, Melka Hombole, Melka Kunturi and Awash bello) gauge stations were obtained from Ministry of Water Irrigation and Electricity, Hydrology Department, Ethiopia. These daily river discharges and sediment concentrations at Hombole gauge station were used for model calibration and validation.

*3.4.3.2* SWAT Model set-up

**A, Watershed and Channel Delineation**

The DEM is used to derive the watershed boundary, channel network, and sub basin size and distribution. The Upper Awash basin was delineated with an outlet point at the out let of the watershed. The overall watershed was further broken down into sub-basins based on the algorithms provided by the SWAT model. As a consequence, these sub-basins influence the level of spatial complexity that is represented in the SWAT model. A sub-basin in SWAT is defined as the hydrologic area contributing to only one stream channel. Stream channels were defined as DEM cells having at least a 500 hectare contributing area. The first step in initializing a watershed simulation in SWAT model is to delineate the watershed and partition into sub basins. SWAT allows the user to delineate the watershed and sub basins using the Digital Elevation Model (DEM). DEM is a grid of square cells where each cell represents the elevation value at that location and the elevation value for each cell is an average of overall elevations inside the cell. The size of each cell determines the resolution of the DEM.

The watershed delineation tool uses and expands the Arc GIS, spatial analyst functions to perform watershed delineation (Neitsch et al, 2011) and stream network was defined for the whole DEM by the model using the concept of flow direction and flow accumulation. To define the origin of streams a threshold area was determined by the user and this threshold area defines the minimum drainage area required to form the origin of a stream. The size and number of sub-basins and details of stream network depends on this threshold area (Winchell et al, 2007).the watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineates a watershed area 10,553.84 km$^2$ with 33 sub-basins (Figure 3.9).

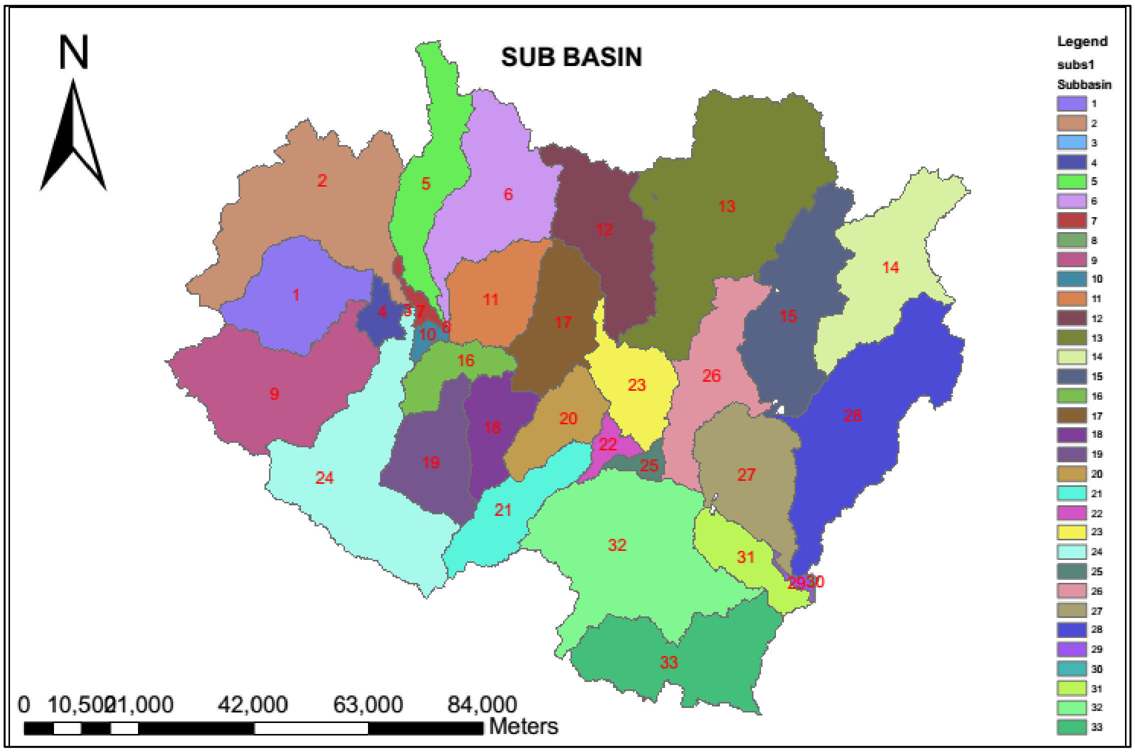



Figure 3.9. The delineated watershed and sub-basins by SWAT model

**B, Hydrologic Response Unit Analysis**

In SWAT, HRUs are defined as being unique occurrences of soil type, land cover, and slope class. Any parcels of land within one sub basin that share the same combination of these three features will be considered one HRU. All processes modeled by SWAT are done for each unique HRU in the watershed, independent of position within each sub basin. Multiple HRU slope discretization were selected for simplicity & saving time during parameterization of the HRU.

In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils, which cover less than the threshold level, are eliminated. The land use, soil and slope map of catchments were overlaid to produce a hydrologic response group by setting a thresh hold value of 5, 20 and 20 % for land use, soil and slope domination to which land use percentage over the sub basin, soil over the land use and slope class percentage over the land use respectively were adopted in these study during HRU definition. Those thresholds were selected by considering the effect on the formulation of hydrologic response and for making the HRU formulation in a manageable amount.

**C, Write Input Tables**

After Hydrologic Response Units parameterization, the next step in SWAT model set-up is writing the input tables. In this section the prepared batch file's containing the location and elevation of weather generator gauge stations, rainfall gauge stations, temperature gauge stations, relative humidity gauge stations, solar gauge stations and wind gauge stations were loaded sequentially. Then SWAT calls each metrological data's related to each batch file and write it to the database for each sub-basin.

*4.2.3.3. SWAT Model Simulation, Sensitivity Analysis, Calibration and Validation*

After the model was set up, the next step was to run the model and the result from the simulation cannot be directly used for further analysis. Instead, the ability of the model to sufficiently predict the constituent stream flow and sediment yield should be evaluated through sensitivity analysis, model calibration and model validation (White & Chaubey, 2005).

**A, Sensitivity analysis**

Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or on model predictions. Model sensitivity is defined as the change in model output per change in parameter input. Sensitivity analysis describes how model output varies over a range of a given input variable. Some researchers noted that sensitivity analysis and calibration are difficult with large number of parameters. (Lenhart et al, 2002), reviewed more than a dozen sensitivity analysis techniques. In general, an important aim of the parameter sensitivity analysis is to allow the possible reduction in the number of parameters that must be estimated, thereby reducing the computational time required for model calibration

When a SWAT simulation is taken place there will be discrepancy between measured data and simulated results.  So, to minimize this discrepancy, it is necessary to determine the parameters which are affecting the results and the extent of variation. Hence, to check this, sensitivity analysis is one of SWAT model tool to show the rank and the mean relative sensitivity of parameters identification and this step was ordered to analysis. This appreciably eases the overall calibration and validation process as well as reduces the time required for it. Besides, as (Lenhart et al, 2002)indicated, it increases the accuracy of calibration by reducing uncertainty. The sensitivity analysis method implemented in SWAT is called the Latin Hypercube One-At–a-Time (LH-OAT) design as proposed by (Morris, 1991) .The four class sensitivity classes are shown in Table below.

Once the SWAT model for the Upper Awash basin was compiled using SWAT interface, a stream flow and sediment yield sensitivity analysis was performed on model parameters. This was done to identify the influential parameters on the modeled stream flow. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization. The sensitivity analysis was performed using SWAT interface for a period of 1990-2007. It was checked at outlet points of upper awash basin the sensitivity analysis showed that 28 parameters were sensitive.

Table 3.5 Sensitivity class for SWAT model

| **Class** | **Index(I)** | **Sensitivity** |
|---|---|---|
| I | $0.00 \leq \mathbf{I} < 0.05$ | Small to Negotiable |
| II | $0.05 \leq \mathbf{I} < 0.02$ | Medium |
| III | $0.02 \leq \mathbf{I} < 1$ | High |
| IV | $\mathbf{I} \geq 1$ | Very high |

Source: (Lenhart et al, 2002)

**B, Model calibration**

Model calibration is a means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted. Similarly, model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch et al, 2011) at different spatial and temporal scales.

Parameter estimation for calibration follows various techniques designed to reduce the uncertainty in the estimates of the process parameters. A typical approach is to first select an initial estimate for the parameters, somewhere inside the ranges previously specified. The parameter values are then adjusted to more closely match the model behavior to that of the watershed. The process of adjustment can be done manually or using computer-based automatic methods. The manual method is the most common, and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite. In sediment transporting modelling two-step calibration procedures has been suggested by (Neitsch et al, 2011), the first is to check water balance contribution, then calibrate stream flow and followed by sediment calibration.

After each calibration, checking the $R^2$, NSE and PBIAS values and calibrate at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$, NSE > 0.5 and PBIAS < ±15 (Santhi et al, 2001). Calibration of stream flow and sediment yield carried out at outlet of sub basin 32 (near outlet of the Basin).

**C, Model Validation**

Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under somewhat different management scenarios. Flow and sediment validation was carried out at a station similar to the calibration. The statistical criteria (the $R^2$, $N_{SE}$ and PBIAS) used during the calibration procedure were also checked here to make sure that the simulated values is still within the accuracy limits. $R^2 > 0.6$, NSE > 0.5 and PBIAS < ±20 (Santhi et al, 2001).

After calibration of flow with the given time step the next step was calibration of sediment yield of the watershed. Like flow calibration, it was calibrated based on sensitive parameters that observed at sensitivity analysis of sediment flow.

Based on the available model input data parameters periods of modeling are:

- Warm Up period (1990-1991)
- Flow and Sediment Sensitivity Period (1990-2007)
- Flow and Sediment calibration period (1992-2007)
- Flow and Sediment Validation period (2008-2014)

## CHAPTER FOUR

# 4 RESULTS AND DISCUSSION

## A. Data Quality Assessed

The time series of rainfall and flow for all stations have been tested for the absence of trend, stationerity, relative & absolute homogeneity and consistency, all the stations had passed the test proving the historical dataset's are used for further analysis.

**Test for Relative Homogeneity**: the graphical sketch of the non-dimensional plot was conducted showing all the stations are homogeneous without sign of inhomogeneity.

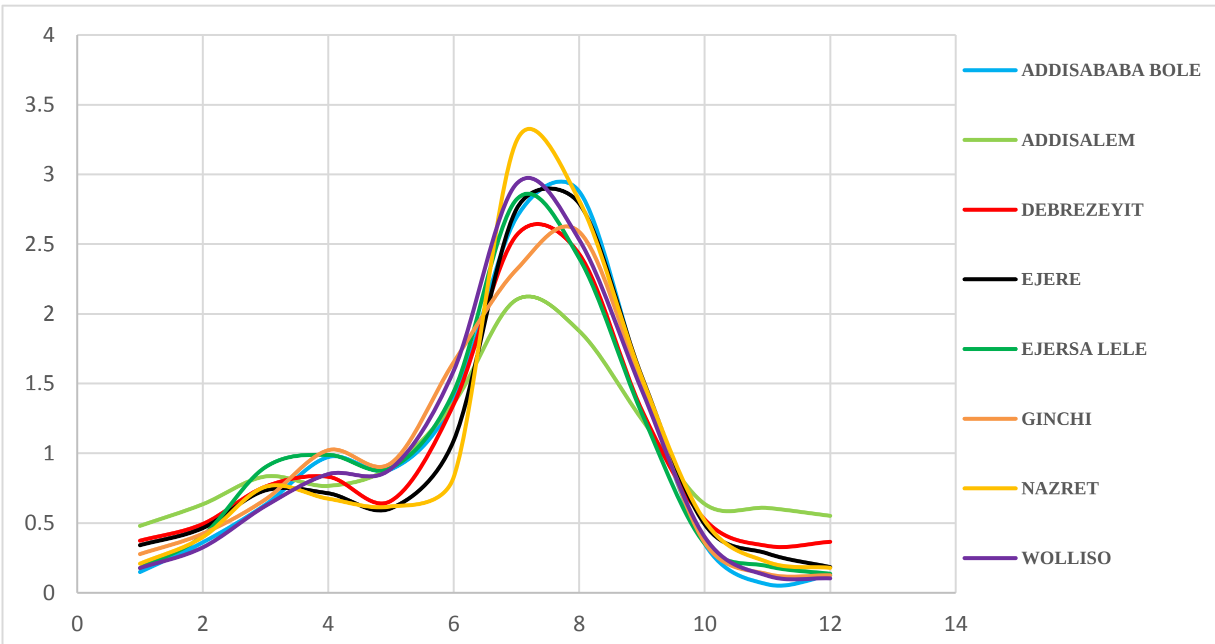



Figure 4.1: Result of relative homogeneity test for selected rainfall stations

**Test for Consistency:** the graphical sketch below shows there is no slope variation in between the time series data of all rainfall station and all the selected stations are consistent (Figure 4.2).

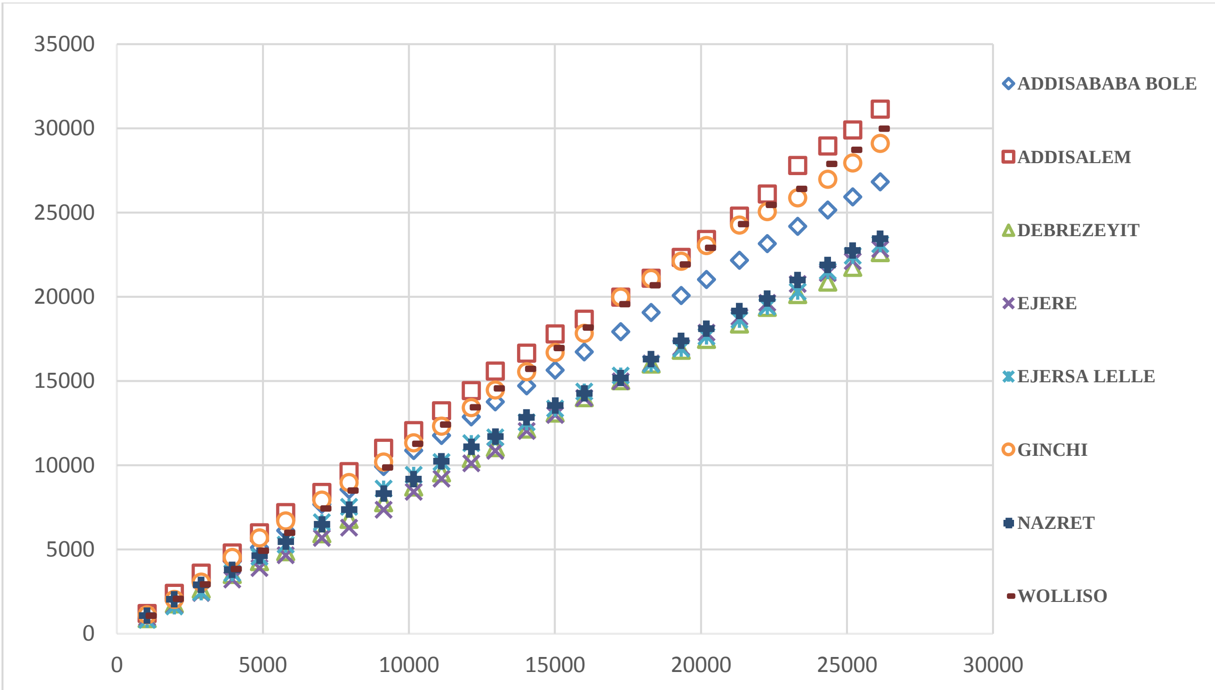



Figure 4.2 Double mass curve showing consistency for selected stations

**Sediment Rating Curve:** The measured sediment load has varied at the same flow record which might be due to measurement error or other uncertainties that occur during the recording period. The developed sediment rating curve was:-

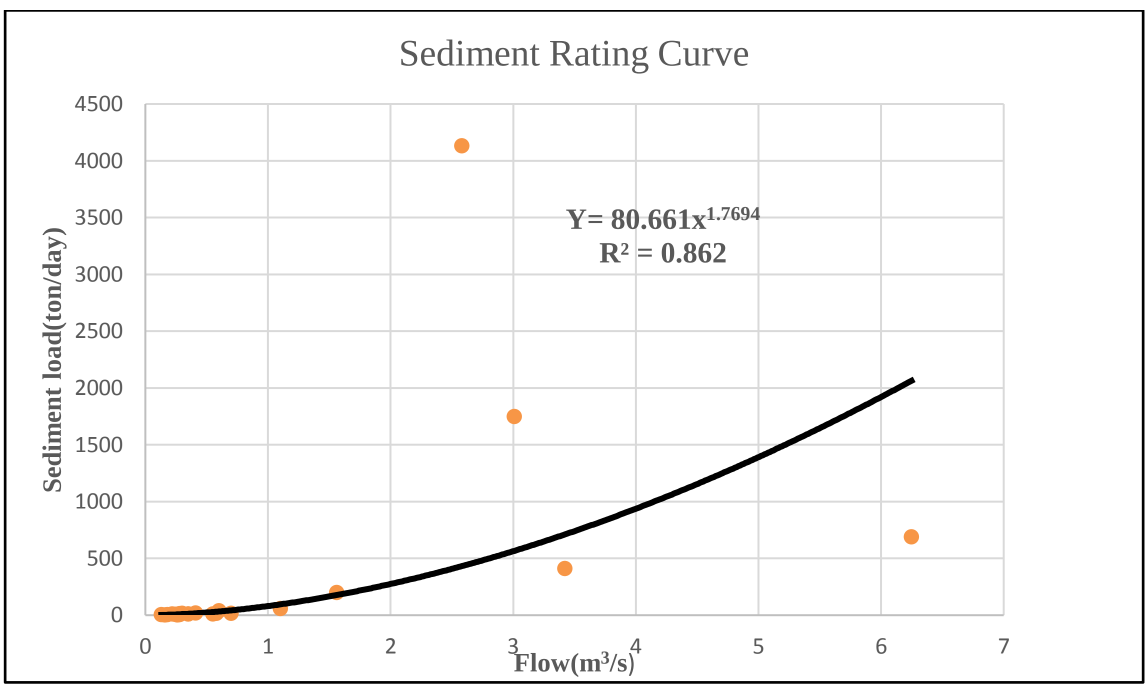



Figure 4.3 Sediment rating curve developed for Hombole gauging station

## 4.1 Stream flow Modeling

### 4.1.1 Flow Simulation and sensitivity analysis

Sensitivity analysis was carried out to identify which model parameter is most important or sensitive. Flow sensitivity analysis was carried out for a period of eighteen years, which includes both two year of warm-up period (from January 1, 1990 to December 31, 1991) and the calibration period (from January 1, 1992 to December 31, 2007).

About 270, iteration has been done by SWAT sensitivity analysis for flow calibration, and 27 parameters were reported as sensitive in different degree of sensitivity for flow. Among 27 flow parameters, only eleven sensitive parameters are identified for the model to avoid model over parameterization. From the eleven sensitive parameters soil evaporation compensation factor (Esco), available water capacity of the soil layer (Sol_Awc) and curve number (CN2) are the most sensitive parameters for 1990 and 2013 LULC data. (Table 4.1 and Table 4.1).

Table 4.1 Selected sensitive parameters of Upper awash basin using 1990 LULC

| **Parameters Description** | **Parameter Code** | **Rank** | **Mean Sensitivity** | **Category of Sensitivity** |
|---|---|---|---|---|
| Soil evaporation compensation factor | Esco | 1 | 0.2270 | High |
| Available Water capacity pf the soil layer(mm) | Sol_Awc | 2 | 0.1630 | High |
| SCS_CN fot moisture condition II9unitless) | Cn2 | 3 | 0.1510 | High |
| maximum potential leaf area index | Blai | 4 | 0.0799 | High |
| Thresh hold depth of water in the shallow aquifer required for evaporation to occur | Revapmn | 5 | 0.0776 | High |
| Soil depth | Sol_Z | 6 | 0.0746 | High |
| Thresh fold depth of water in the shallow aquifer required for return flow to occur(mm) | Gwqmn | 7 | 0.0685 | High |
| Base Flow alpha factor | Alpha_Bf | 8 | 0.0416 | Medium |
| Maximum canopy Index(mm) | Canmax | 9 | 0.0394 | Medium |
| Effective Channel Hydraulic conductivity(mm/h) | Ch_K2 | 10 | 0.0257 | Medium |
| Ground water evaporation coefficient | GW_Revap | 11 | 0.0254 | Medium |

Table 4.2 Selected sensitive parameters of Upper awash basin using 2013 LULC

| **Parameters Description** | **Parameter Code** | **Rank** | **Mean Sensitivity** | **Category of Sensitivity** |
|---|---|---|---|---|
| Soil evaporation compensation factor | Esco | 1 | 0.227 | High |
| Available Water capacity pf the soil layer(mm) | Sol_Awc | 2 | 0.134 | High |
| SCS_CN for moisture condition II9unitless) | Cn2 | 3 | 0.124 | High |
| Thresh hold depth of water in the shallow aquifer required for evaporation to occur | Blai | 4 | 0.0979 | High |
| Thresh hold depth of water in the shallow aquifer required for evaporation to occur | Revapmn | 5 | 0.0812 | High |
| Soil depth | Sol_Z | 6 | 0.0803 | High |
| Thresh fold depth of water in the shallow aquifer required for return flow to occur(mm) | Gwqmn | 7 | 0.0795 | High |
| Maximum canopy Index(mm) | Canmx | 8 | 0.0672 | High |
| Base Flow alpha factor | Alpha_Bf | 9 | 0.0433 | Medium |
| Ground water evaporation coefficient | GW_Revap | 10 | 0.0322 | Medium |
| Effective Channel Hydraulic conductivity(mm/h) | Ch_K2 | 11 | 0.0256 | Medium |

The result denotes that ground water parameters like threshold depth of water in the shallow aquifer required for return flow to occur (Gwqmn), ground water evaporation coefficient (GW_Revap), base flow alpha factor (Alpha_Bf), and threshold depth of water in the shallow aquifer required for evaporation to occur (Revapmn) are found the influencing flow parameters (having relative mean sensitivity from medium to high degree of sensitivity.

Secondly, hydraulic response unit parameters such as maximum potential index (Canmx) , soil evaporation compensation factor (Esco) had influence and the SCS_CN for moisture condition II (Cn2) was found sensitive which indicates that the parameters had a governing effect on simulated surface flow in respective with the observed flow. Finally, the soil parameters inclusive of soil depth (Sol_Z) and soil available water capacity (Sol_Awc) had also contributing effect on stream flow and were taken as a guideline for the calibration.

### 4.1.2 Stream Flow Calibration and Validation

Monthly flow calibration was done for 16 years (from January 1, 1992 to December 31, 2007) at Hombole station, which include 2 years (from January 1, 1990 to December 31, 1991) for model initialization (warm up). Before calibration proceeds, the performance of the model was evaluated from the initial simulation runs with model default parameter values. From this the monthly simulation correlation coefficient ($R^2$) of 0.84, Nash Sutcliffe model efficiency (NSE) of -2.66, Root mean square error observation standard deviation (RSR) of -2.66 and Percent of biased (PBIAS) of -182.44 were obtained from the initial model run. The result shows the performance indicator was out of the acceptable limits, i.e. NSE > 0.5 and PBIAS < ±15% (Santhi et al, 2001). The model flow parameters were required for an adjustment and this adjustment was based on the sensitivity analysis result of flow parameters (Table 4.1. and Table 4.2.).

Model parameters were calibrated manually .The calibration processes considered the parameters and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The initial/default and finally calibrated values are shown in Table 4.4 and Table 4.5 for both 1990 and 2013 LULC respectively.

Based on the compiled indicators, the performance of the model has been evaluated. The evaluation of the model accuracy based on performance rating: Very good, Good, Satisfactory and Unsatisfactory (Moriasi et al., 2007).

Table 4.3 Model Performance Rating (adopted from Moriasi et al., 2007)

| **Rating** | **RSR** | **NSE** | **PBIAS** | | |
|---|---|---|---|---|---|
| | | | **Flow** | **Sediment** | **N, P** |
| Very Good | 0.00 - 0.5 | 0.75-1 | < 10 | < 15 | < 25 |
| Good | 0.5 - 0.6 | 0.65 - 0.75 | 10-15 | 15-30 | 25-45 |
| Satisfactory | 0.6 - 0.7 | 0.5 - 0.65 | 15-25 | 30-55 | 40-70 |
| Unsatisfactory | > 0.7 | < 0.5 | > 25 | > 55 | > 70 |

Table 4.4 Default and calibrated flow parameters of the watershed using 1990 LULC

| Parameter | Range | Initial/Default Value | Adjusted value |
|---|---|---|---|
| Esco | 0-1 | 0.95 | 0.3 |
| Sol_Awc | ±25% | Default* | 25% |
| Cn2 | ±25% | Default* | -25% |
| Blai | ±25% | Default* | 25% |
| Revapmn | 0-500 | 1 | 350 |
| Sol_Z | ±25% | Default* | 20% |
| Gwqmn | 0-5,000 | 0 | 4500 |
| Alpha_Bf | 0-1 | 0.048 | 0.085 |
| Canmax | 0-10 | 0 | 5 |
| Ch_K2 | 0-150 | 0 | 30 |
| GW_Revap | 0.02-0.2 | 0.02 | 0.2 |

Table 4.5 Default and calibrated flow parameters of the watershed using 2013 LULC

| Parameter | Range | Initial/Default Value | Adjusted value |
|---|---|---|---|
| Esco | 0-1 | 0.95 | 0.3 |
| Sol_Awc | ±25% | Default* | 25% |
| Cn2 | ±25% | Default* | -25% |
| Blai | ±25% | Default* | +15% |
| Revapmn | 0-500 | 1 | 250 |
| Sol_Z | ±25% | Default* | 20% |
| Gwqmn | 0-5,000 | 0 | 4500 |
| Canmax | 0-10 | 0 | 3 |
| Alpha_Bf | 0-1 | 0.048 | 0.085 |
| GW_Revap | 0.02-0.2 | 0 | 0.2 |
| Ch_K2 | 0-150 | 0.02 | 30 |

The model goodness-of-fit was evaluated and the model performance after adjusting all the above parameters. Calibration resulted after simulation found for 1990 LULC to be Correlation coefficient ($R^2$) of 0.86, Nash Sutcliffe model efficiency (NSE) of 0.83, Root mean square error observation standard deviation (RSR) of 0.17 and Percent of biased (PBIAS) of -5.18. While, for 2013 LULC, Correlation coefficient ($R^2$) of 0.83, Nash Sutcliffe model efficiency (NSE) of 0.78, Root mean square error observation standard deviation (RSR) of 0.22 and Percent of biased (PBIAS) of -23.78 showing a good agreement between measured and simulated monthly flows and indicated in Table 4.6 and Table 4.7 respectively. The result also indicated that the model was calibrated satisfactorily to simulate monthly stream flows adequately. The calibration result demonstrates SWAT's ability to predict realistic flow.

Table 4.6 Calibration result statistic for monthly measured and simulated stream flow using 1990 LULC

| **Monthly time step simulation** | **Mean Monthly Stream flow($m^3$/s)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Calibration period (1992-2007) | 43.45 | 45.7 | 0.86 | 0.17 | 0.83 | -5.18 |

Table 4.7 Calibration result statistic for monthly measured and simulated stream using 2013 LULC.

| **Monthly time step simulation** | **Mean Monthly Stream flow($m^3$/s)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Calibration period (1992-2007) | 43.45 | 53.78 | 0.83 | 0.22 | 0.78 | -23.78 |

During the calibration period (1992 to 2007), the simulated monthly flows matched well with the measured monthly flows ($R^2$= 0.83, RSR=0.17, PBIAS=-5.18 and NSE= 0.86) and ($R^2$= 0.83, RSR=0.22, PBIAS=-23.78 and NSE= 0.78) as shown in Table 4.6. and Table 4.7. for both 1990 and 2013 LULC respectively. The trends of seasonal variability and monthly average discharge were generally well captured. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volumes (as for example in August 2006). However, the model over estimates (August of 1994, 1999, 2002 and 2006) and under estimate (August of 1992, 1993, 1995, 1996, 1998, 2000, 2003, 2004, 2005 and 2007) the peak monthly flow in most of the simulation periods for 1990 LULC. It over estimates (August of 1992, 1993, 1994, 1995, 1997, 1999, 2000, 2001,2003, 2005, 2006 and 2007) and under estimate (August of 1996, 2002and 2004) the peak monthly flow in most of the simulation periods for 2013 LULC (Figures 4.1. and 4.3.).

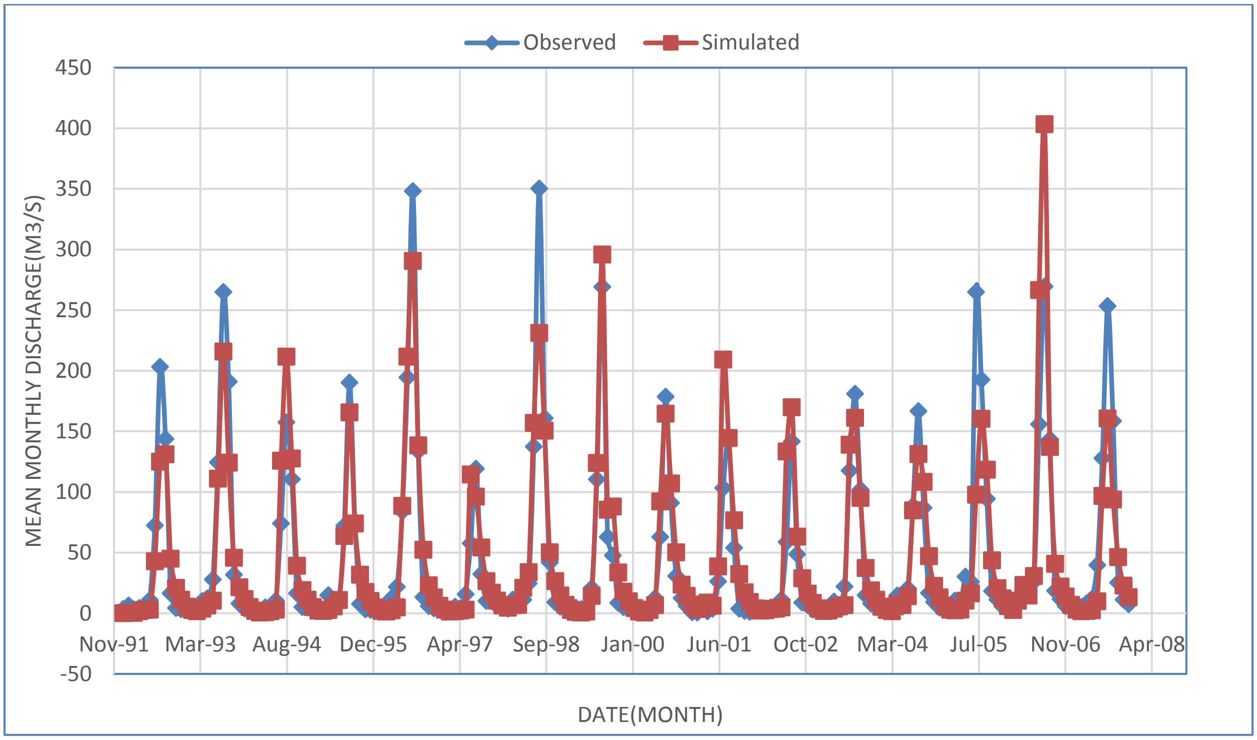



Figure 4.4. Calibration result of average monthly observed and simulated flow hydrograph (1992-2007) for 1990 LULC

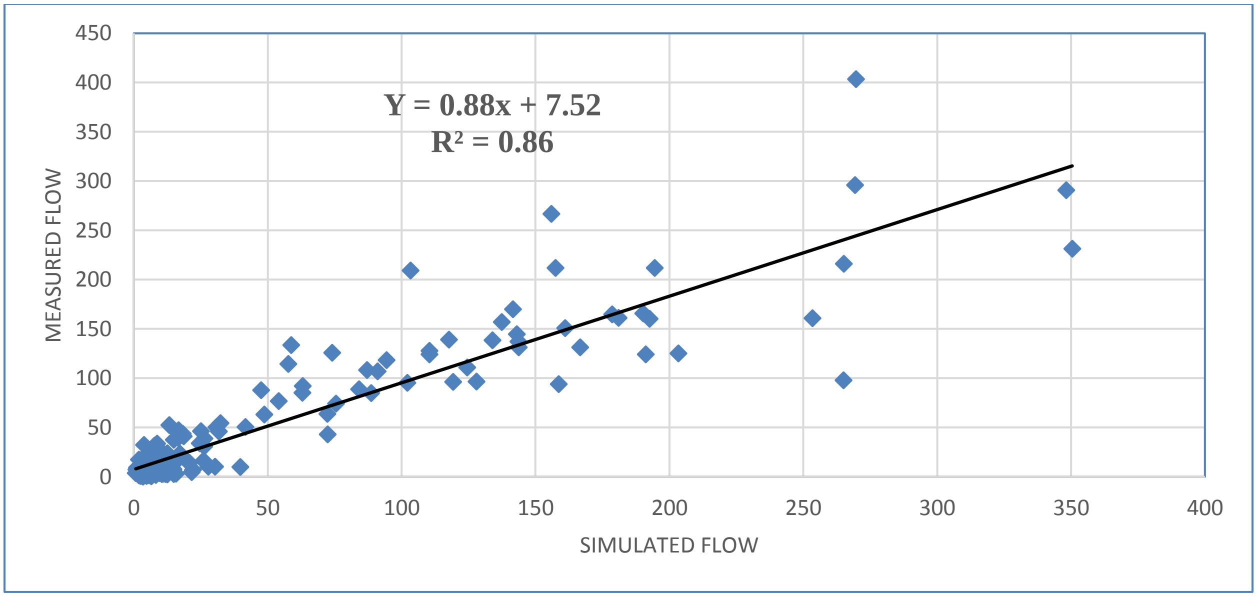



Figure 4.5. Regression analysis of simulated versus observed monthly flow during calibration period (1992-2007) for 1990 LULC

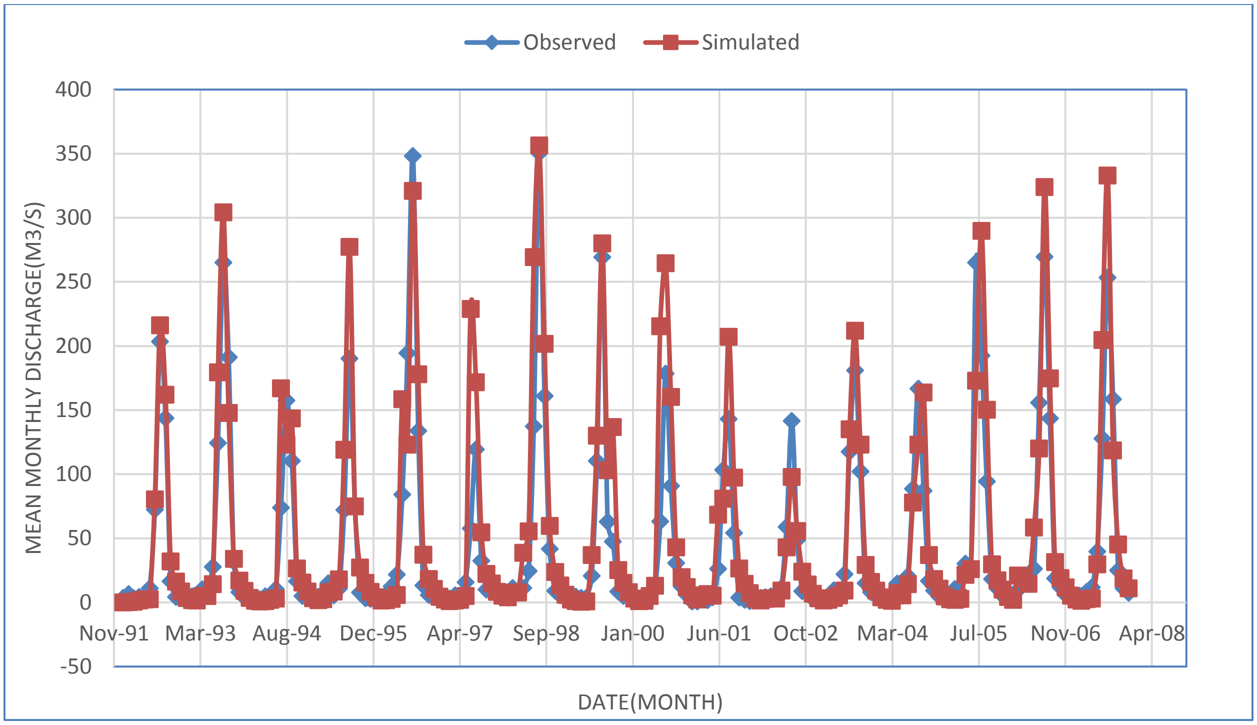



Figure 4.6. Calibration result of average monthly observed and simulated flow hydrograph (1992-2007) for 2013 LULC

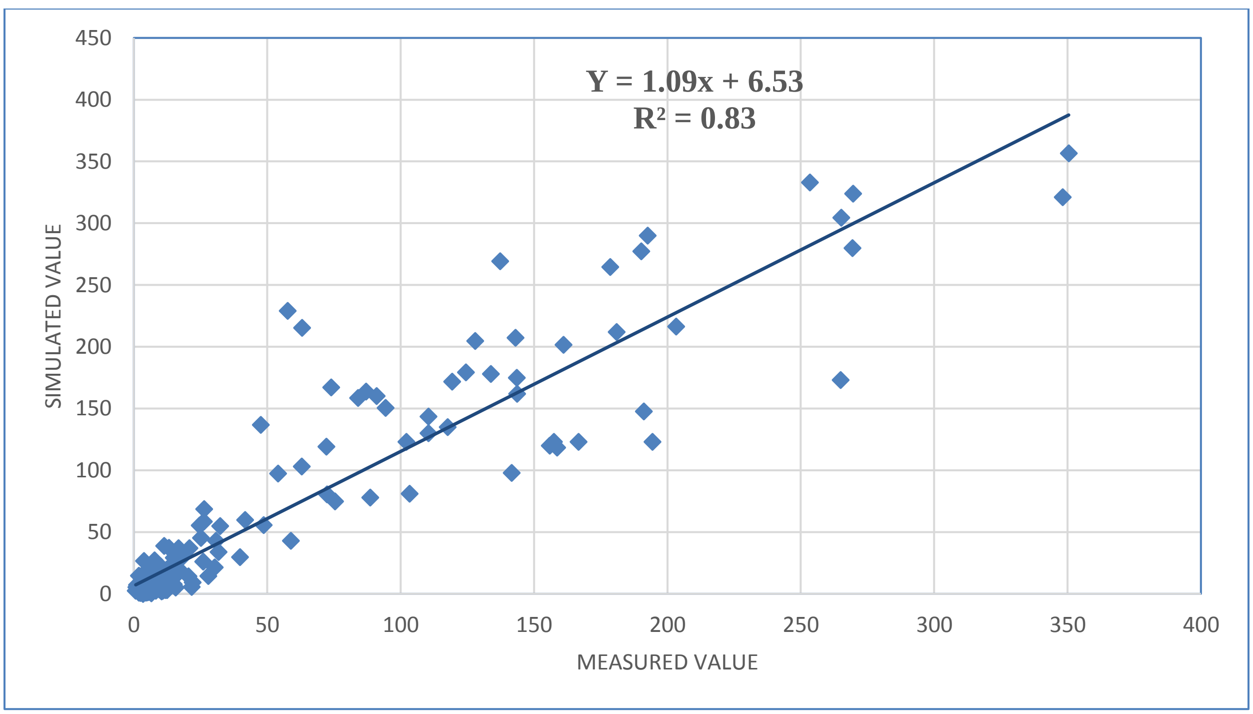



Figure 4.7. Regression analysis of simulated versus observed monthly flow during calibration period (1992-2007) for 2013 LULC

The model with calibrated parameters was validated by using an independent set of measured flow data which were not used during model calibration. The model performance in validation was carried out from 2008 to 2014, without further adjustment of the parameters of flows. Accordingly, good match between monthly measured and simulated flows in the validation period for 1990 LULC were demonstrated by the Correlation coefficient ($R^2$) of 0.89, Nash Sutcliffe model efficiency (NSE) of 0.8, Root mean square error observation standard deviation (RSR) of 0.20 and Percent of biased (PBIAS) of 3.24. While, for 2013 LULC, Correlation coefficient ($R^2$) of 0.81, Nash Sutcliffe model efficiency (NSE) of 0.81, Root mean square error observation standard deviation (RSR) of 0.19 and Percent of biased (PBIAS) of -20.84 (Table 4.8. and Table 4.9).

Table 4.8 Validation result statistic for monthly measured and simulated stream flow using 1990 LULC

| **Monthly time step simulation** | **Mean Monthly Stream flow($m^3/s$)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Validation period (2008-2014) | 44.25 | 42.81 | 0.89 | 0.20 | 0.80 | 3.24 |

Table 4.9 Validation result statistic for monthly measured and simulated stream flow using 2013 LULC

| **Monthly time step simulation** | **Mean Monthly Stream flow($m^3/s$)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Validation period (2008-2014) | 44.25 | 53.47 | 0.81 | 0.19 | 0.81 | -20.84 |

The hydrograph of the validation period of the observed and simulated flow in monthly estimation, the model slightly over estimates pick flows like July of 2010 and under estimates some of the months peak flows like August of 2008, 2009, 2012, 2014 in period of validation period for 1990 LULC. It slightly over estimates pick flows like August of 2008, 2010, 2012 and 2014 and under estimates some of the months peak flows like August of 2009, and 2013 in period of validation period for 2013 LULC. (Figure 4.5 and 4.7). This may be resulted from the quality of weather or flow data used as an input to the model.

Some of the stations have many missing weather data, which were left out to be estimated and filled by the model's weather generator. Using estimated data may influence the simulation output. Additionally, mistake in measurement of flow and weather data may be another reason for the slight variation between measured and simulated flows at peak and under discharges.

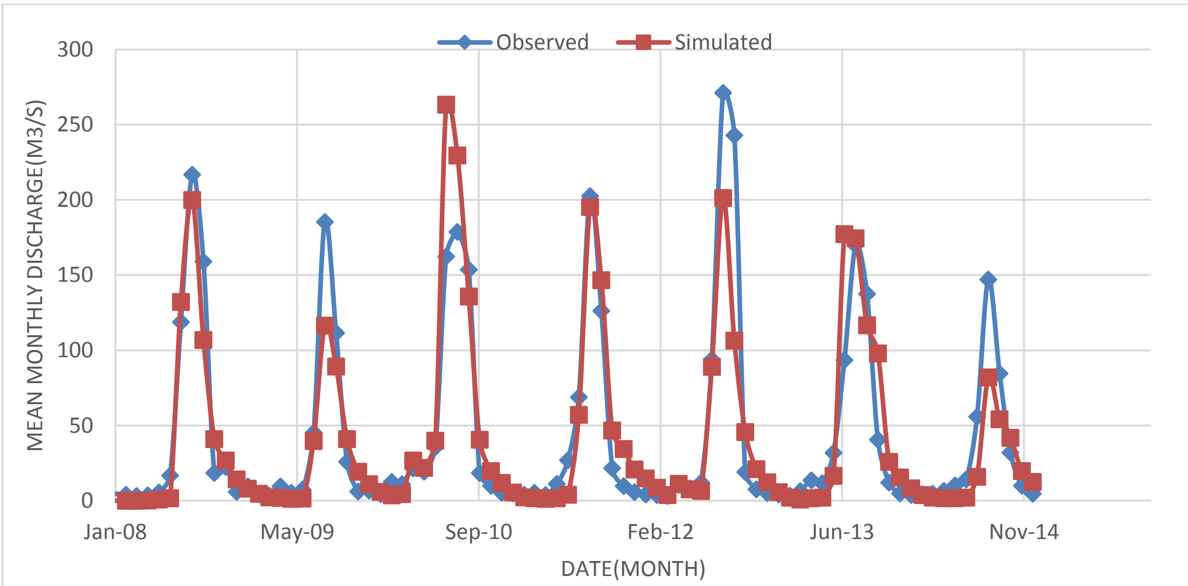



Figure 4.8. Validation result of average monthly observed and simulated flow hydrograph (2008-2014) for 1990 LULC

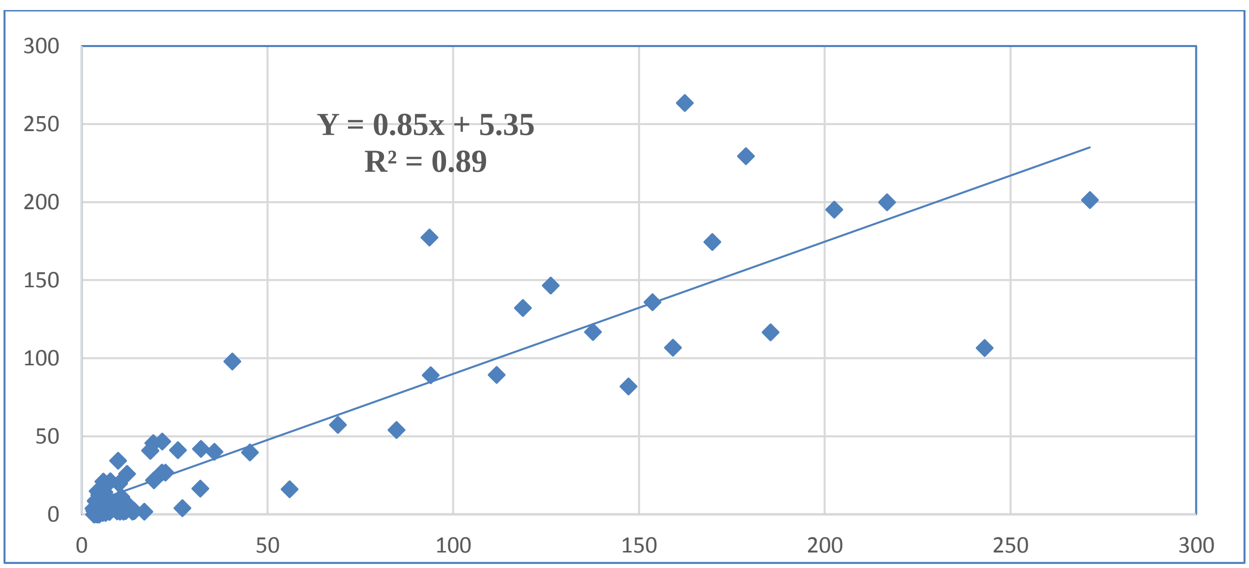



Figure 4.9. Regression analysis of simulated versus observed monthly flow during Validation period (2008-2014) for 1990 LULC

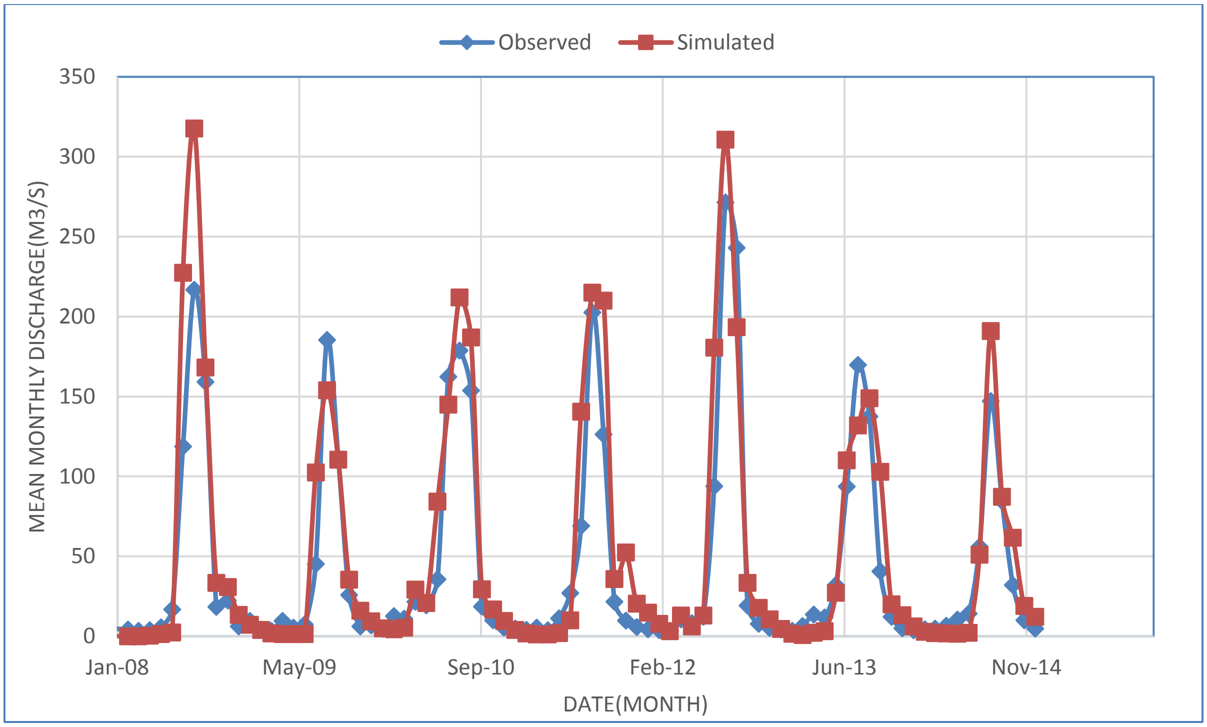



Figure 4.10. Validation results of average monthly observed and simulated flow hydrograph (2008-2014) for 2013 LULC

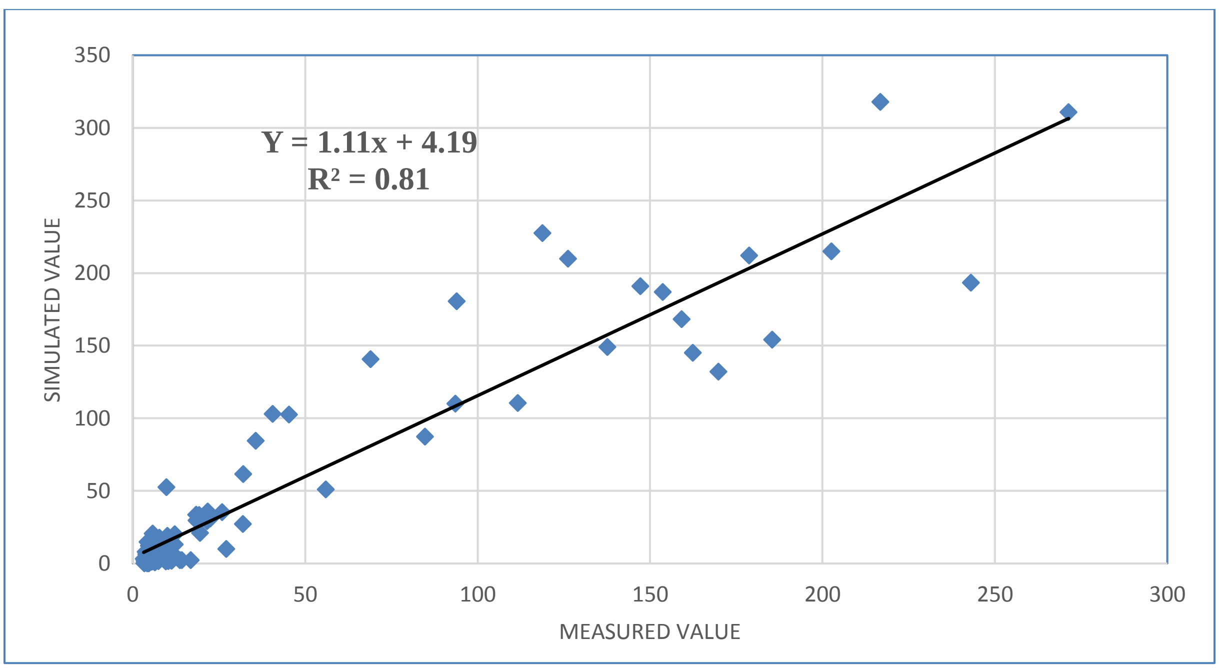



Figure 4.11. Regression analysis of simulated versus observed monthly flow during validation period (2008-2014) for 2013 LULC

### 4.2 Sediment Yield Modeling

#### 4.2.1 Sediment Yield Simulation and Sensitivity Analysis

Sensitivity analysis was done for sediment yield calibration and validation for both 1990 and 2013 LULC. Sensitivity parameters for sediment yield in the watershed includes USLE support practice factor (USLE_P), linear factor for channel sediment routing (SPCON) and exponential factor for channel sediment routing (SPEXP) were found highly sensitive for sediment flow. While, USLE cover or management factor (USLE_C) was found to be moderately sensitive. From those sensitive parameters USLE support practice factor (USLE_P) was the most sensitive of all (Table 5.9 and 5.10).

Table 4.10 Selected sensitive parameters of Upper awash basin using 1990 LULC

| Parameters Description | Parameter Code | Rank | Mean Sensitivity | Category of Sensitivity |
|---|---|---|---|---|
| Support practice factor | USLE_P | 1 | 2.49 | Very High |
| Linear factor for channel sediment routing | SPCON | 2 | 0.43 | High |
| Exponential factor for channel sediment routing | SPEXP | 3 | 0.09 | High |
| Cover or management practice factor | USLE_C | 4 | 0.04 | Medium |

Table 4.11 Selected sensitive parameters of Upper awash basin using 2013 LULC

| Parameters Description | Parameter Code | Rank | Mean Sensitivity | Category of Sensitivity |
|---|---|---|---|---|
| Support practice factor | USLE_P | 1 | 2.51 | Very High |
| Linear factor for channel sediment routing | SPCON | 2 | 0.4 | High |
| Exponential factor for channel sediment routing | SPEXP | 3 | 0.07 | High |
| Cover or management practice factor | USLE_C | 4 | 0.03 | Medium |

#### 4.2.2 Sediment Yield Calibration and Validation

After sensitivity analysis, the next step was calibrating sediment yield of the watershed. Two years (Jan, 1990 – Dec, 1991) was used for model warm up. So that model was calibrated from 1992 to 2007. The calibration of sediment yield of the watershed was done based on sediment sensitivity analysis that has identified sensitive parameters and has effect on the simulated result when changed for sediment yield of the watershed for both 1990 and 2013 LULC (Table 5.11 and Table 5.12), and by varying iteratively within the allowable ranges of the parameters.

Table 4.12 Default and final calibrated sediment parameters values of Upper awash basin using 1990 LULC

| Parameter | | Range | Initial/Default Value | Adjusted value |
|---|---|---|---|---|
| USLE_P | | 0-1 | 1 | 0.9 |
| SPCON | | 0.001-0.01 | 0.0001 | 0.01 |
| SPEXP | | 1-2 | 1 | 1.8 |
| USLE_C | For plantation | 0.001-0.5 | 0.03 | 0.25 |
| | For cultivation | 0.001-0.5 | 0.03 | 0.5 |
| | For grassland | 0.001-0.5 | 0.003 | 0.4 |
| | For natural forest | 0.001-0.5 | 0.001 | 0.2 |
| | For shrubland | 0.001-0.5 | 0.003 | 0.3 |
| | For wetland | 0.001-0.5 | 0.003 | 0.2 |

Table 4.13 Default and sensitive sediment parameter values of Upper awash basin using 2013 LULC

| Parameter | | Range | Initial/Default Value | Adjusted value |
|---|---|---|---|---|
| USLE_P | | 0-1 | 1 | 0.9 |
| SPCON | | 0.001-0.01 | 0.0001 | 0.01 |
| SPEXP | | 1-2 | 1 | 1.8 |
| USLE_C | For plantation | 0.001-0.5 | 0.03 | 0.25 |
| | For cultivation | 0.001-0.5 | 0.03 | 0.5 |
| | For grassland | 0.001-0.5 | 0.003 | 0.4 |
| | For natural forest | 0.001-0.5 | 0.001 | 0.2 |
| | For shrubland | 0.001-0.5 | 0.003 | 0.3 |
| | For wetland | 0.001-0.5 | 0.003 | 0.2 |

After adjustment of all the above parameters, the model was run again with the calibrated parameters. The model was calibrated for sediment by comparing monthly model simulated sediment load against monthly measured sediment load from Hombole station for the period Jan 1992 to Dec 2007.

During the calibration period (1992 to 2007), the simulated monthly flows matched well with the measured monthly flows ($R^2$= 0.79, RSR=0.25, PBIAS=-18.73 and NSE= 0.75) and ($R^2$= 0.83, RSR=0.22, PBIAS=15.78 and NSE= 0.78) as shown in Table 4.13 and

Table 4.14, for both 1990 and 2013 LULC respectively. Calibration results show that model performance is good with simulation of monthly sediment load.

Table 4.14 Calibration statistic of observed and simulated sediment load using 1990 LULC

| **Monthly time step simulation** | **Over Year Sediment Loading (Ton/ha/yr.)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Calibration period (1992-2007) | 61.96 | 50.35 | 0.79 | 0.25 | 0.75 | 18.73 |

Table 4.15 Calibration statistic of observed and simulated sediment loading using 2013 LULC

| **Monthly time step simulation** | **Over Year Sediment Loading (Ton/ha/yr.)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Calibration period (1992-2007) | 61.96 | 55.22 | 0.81 | 0.22 | 0.78 | 15.72 |

The hydrograph of the calibration period of the observed and simulated sediment load in monthly basis shows the model slightly underestimated almost all of monthly sediment yields of the watershed and slightly overestimate the sediment yield of August 1994, 1997 and 2007 for 1990 LULC and  August 1994, 2000 and July 1997 for 2013 LULC.(Figure 4.9 and 4.11).

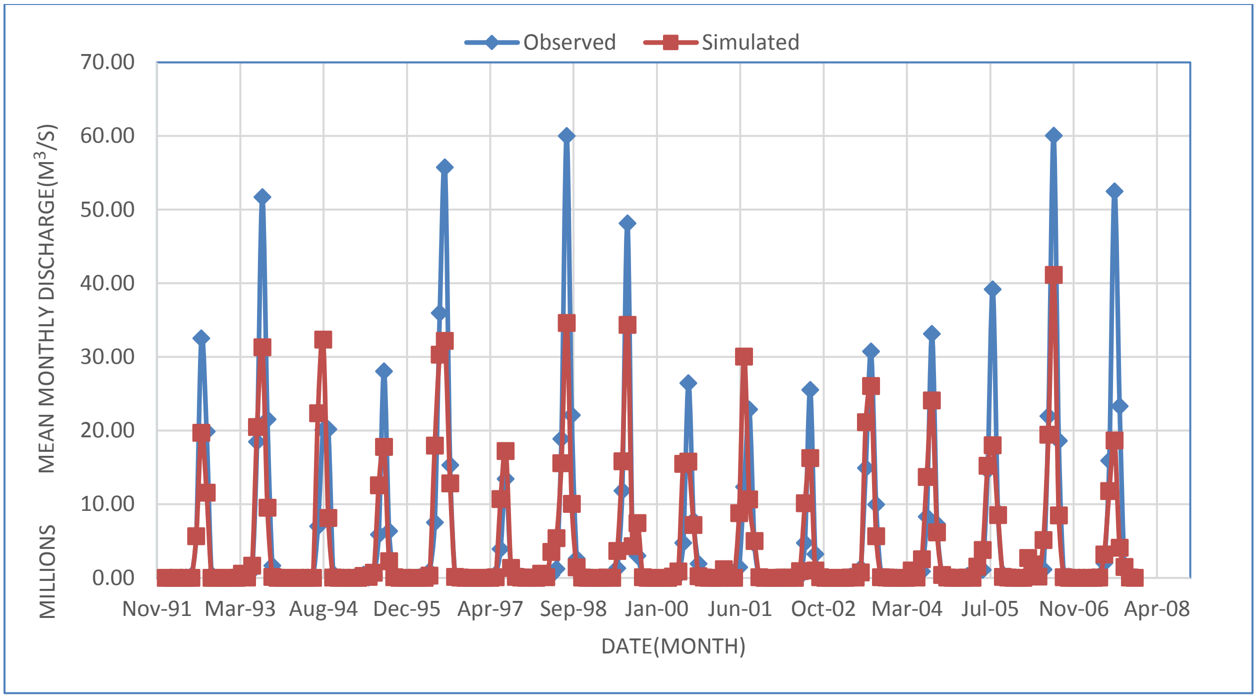



Figure 4.12. Observed and simulated monthly sediment yield in calibration period (1992-2007) for 1990 LULC

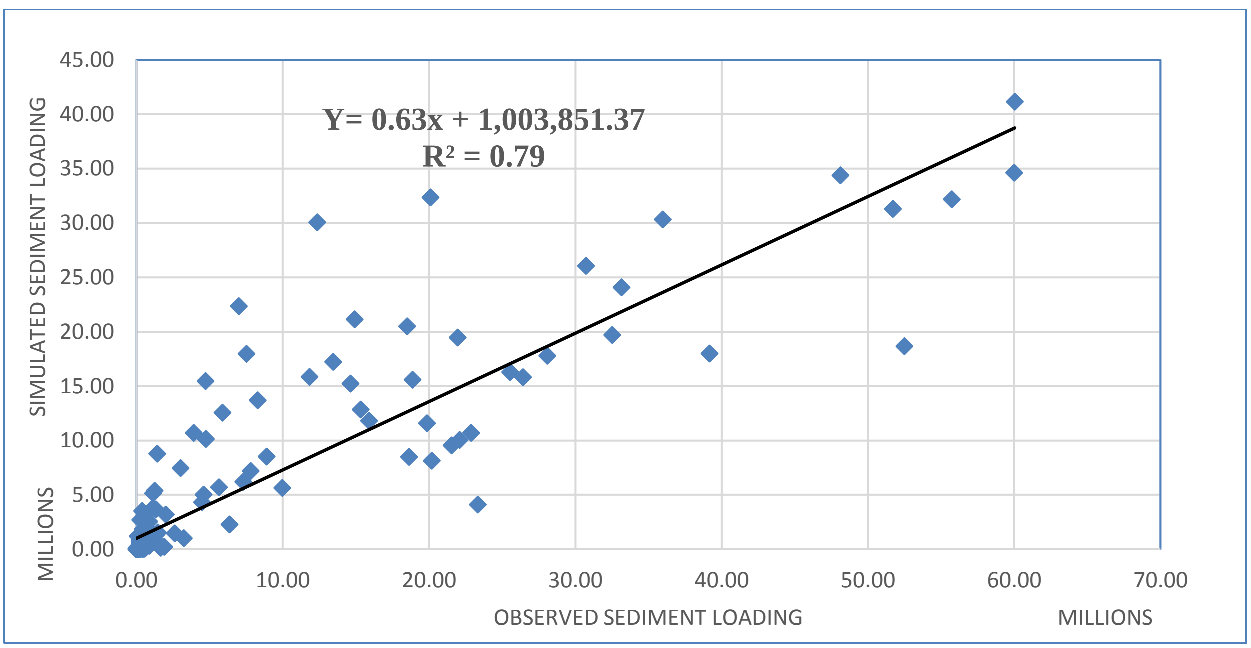



Figure 4.13. Regression analysis of simulated versus observed sediment load during calibration period (1992-2007) for 1990 LULC

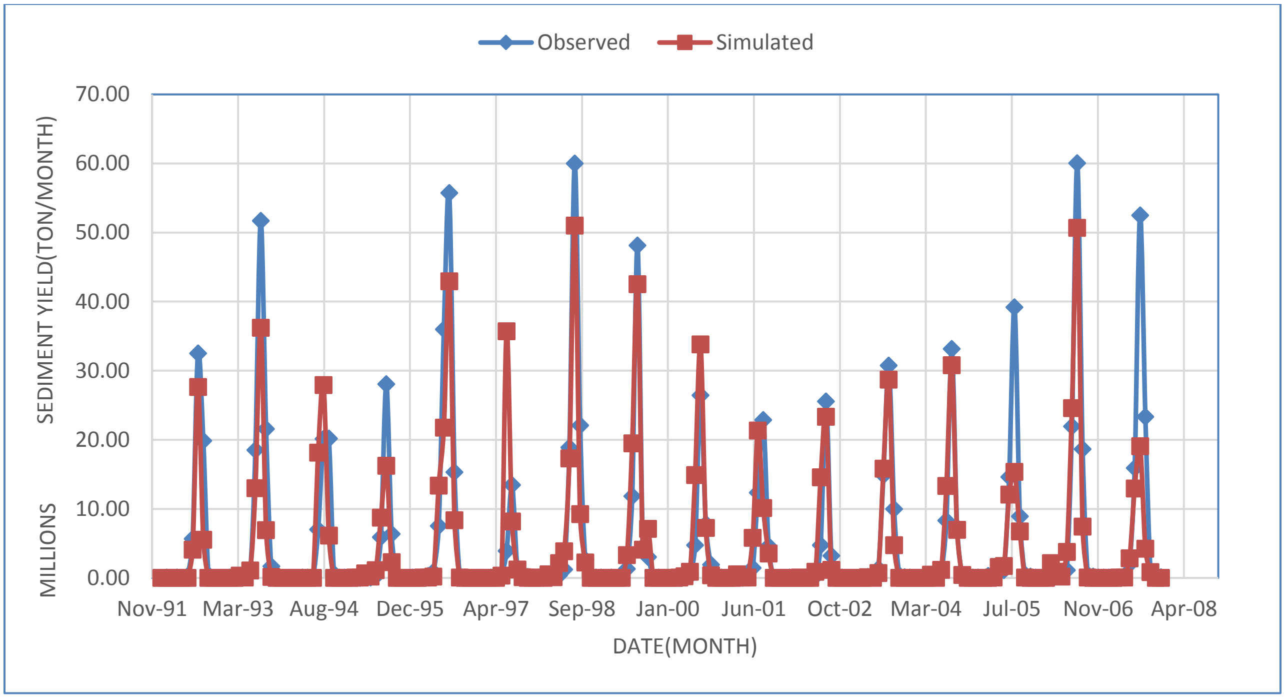



Figure 4.14. Observed and simulated monthly sediment yield in the calibration period (1992-2007) for 2013 LULC

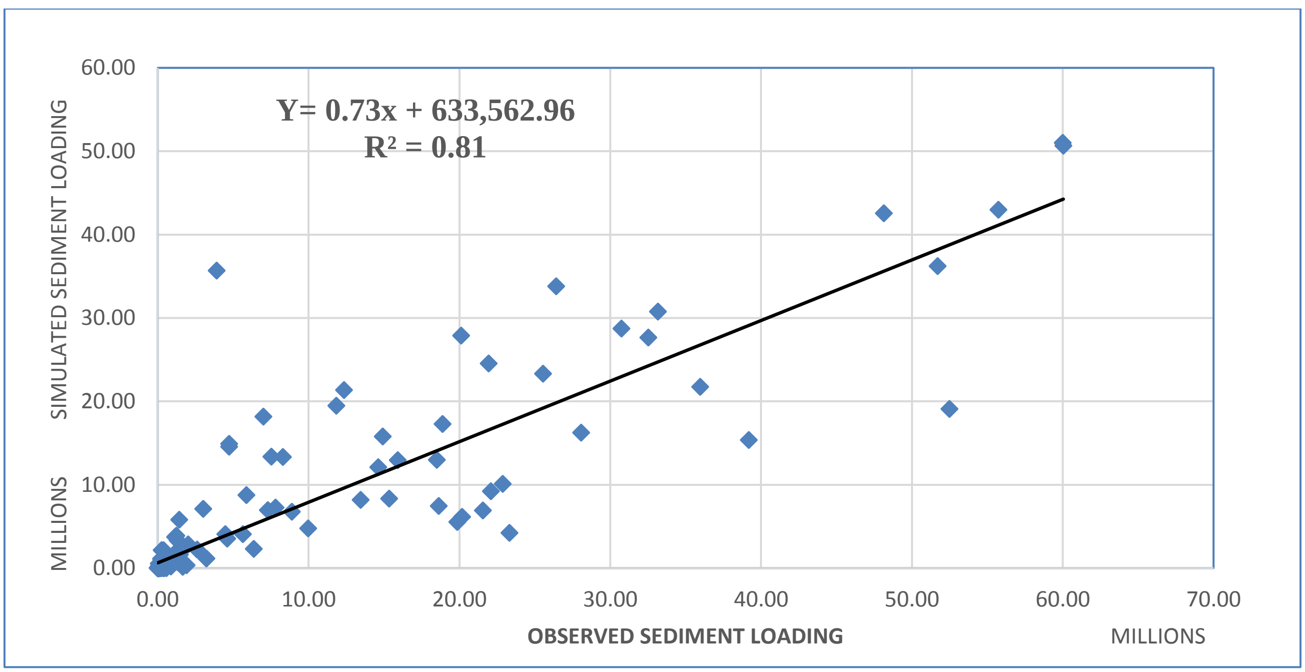



Figure 4.15. Regression analysis of simulated versus observed sediment load during calibration period (1992-2007) for 2013 LULC

After calibration then SWAT model was validated to sediment for the period 2008 to 2014 using the same parameters, which were adjusted during calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically.

The model slightly under estimated high sediment loads (Figure 5.13 and 5.15) in most of calibration and validation periods. Similar to flow, this is may be resulted from limited weather or sediment data used as an input to the model. However, the overall time series trend of the measured sediment load is well explained by the simulated sediment in both calibration and validation periods.

The statistical values in the monthly basis of sediment yield estimation in the validation period results ($R^2$= 0.73, RSR=0.29, PBIAS=21.99and NSE= 0.7) and ($R^2$= 0.72, RSR=0.28, PBIAS=17.62 and NSE= 0.7) as shown in Table 5.15 and Table 5.16, for both 1990 and 2013 LULC. The observed and simulated sediment yield in monthly time step of the validation period shows that model slightly under estimate the sediment yields of highly flow time periods except July 2010.

Table 4.16 Validation statistic of observed and simulated sediment load using 1990 LULC

| **Monthly time step simulation** | **Over Year Sediment Loading (Ton/ha/yr.)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Validation period (2008-2014) | 55.80 | 43.53 | 0.73 | 0.29 | 0.70 | 21.99 |

Table 4.17 Validation statistic of observed and simulated sediment load using 2013 LULC

| **Monthly time step simulation** | **Over Year Sediment Loading (Ton/ha/yr.)** | | **Model Performance** | | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | $R^2$ | RSR | NSE | PBIAS |
| Validation period (2008-2014) | 55.80 | 40.97 | 0.72 | 0.28 | 0.72 | 17.62 |

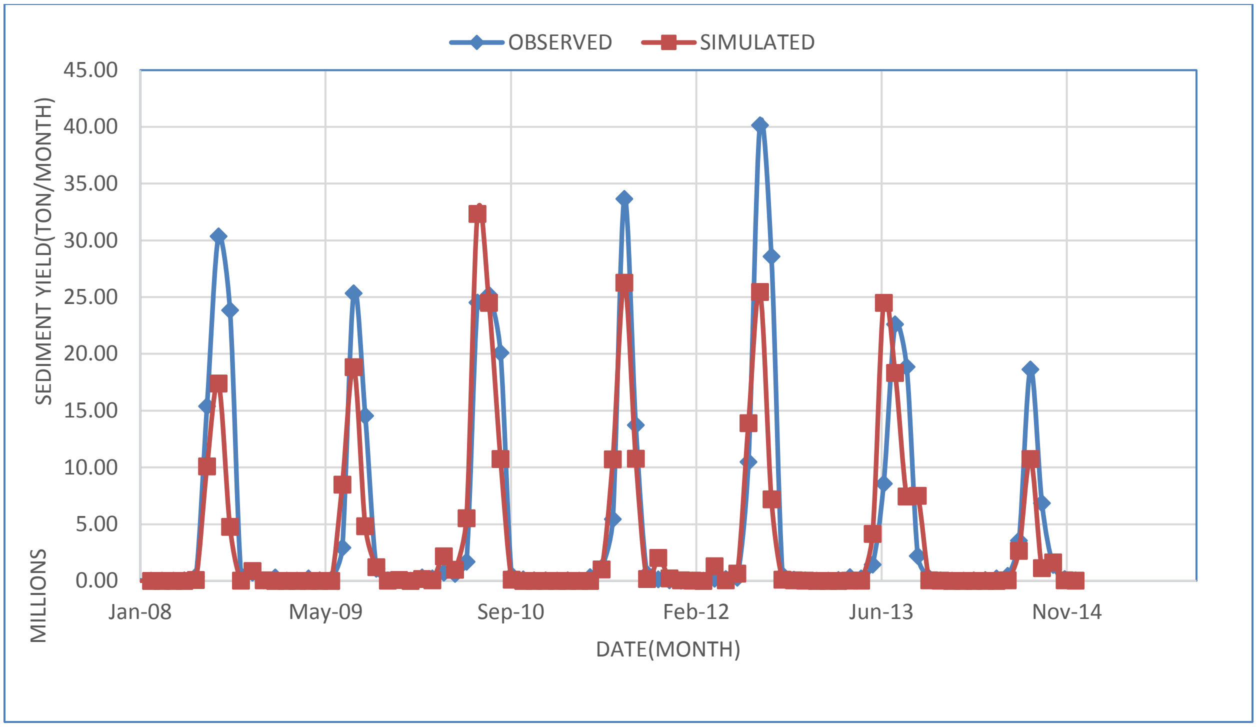



Figure 4.16. Observed and simulated monthly sediment yield in the validation period (2008-2014) for 1990 LULC

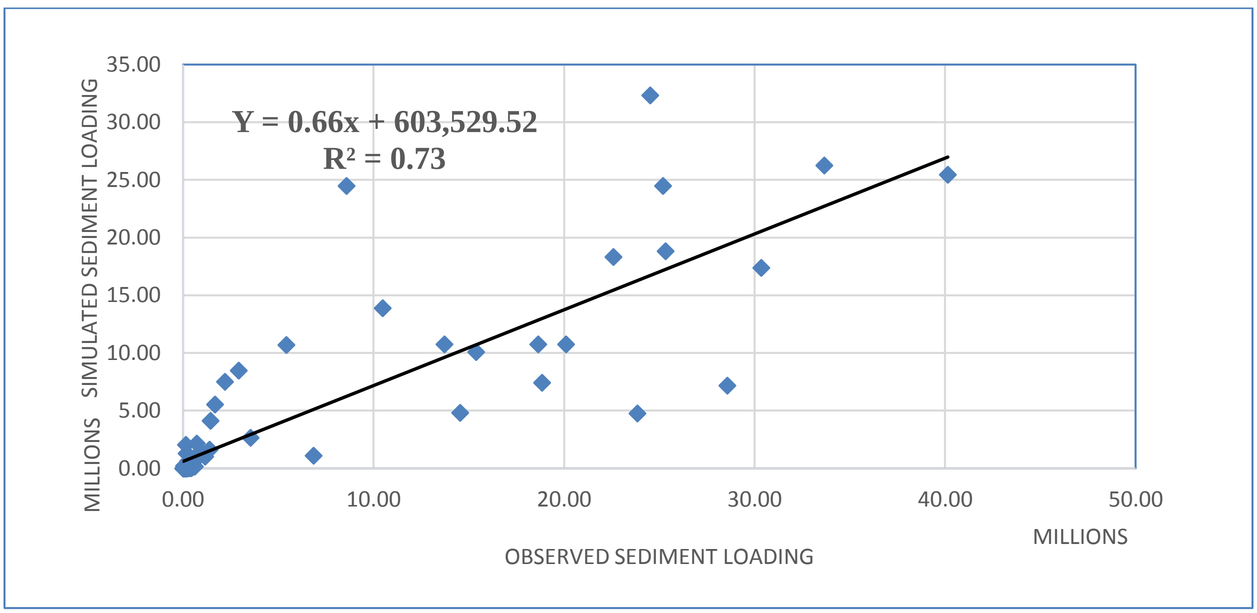



Figure 4.17. Regression analysis of simulated versus observed sediment load during validation period (2008-2014) for 1990 LULC

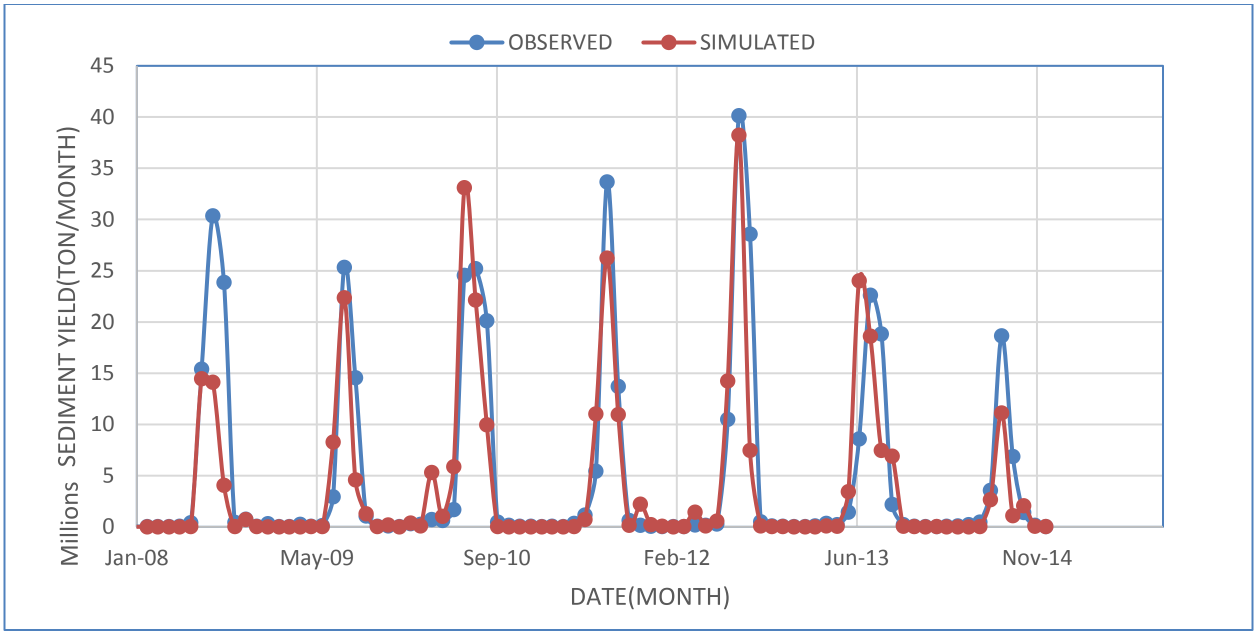



Figure 4.18. Observed and simulated monthly sediment yield in the validation period (2008-2014) for 2013 LULC

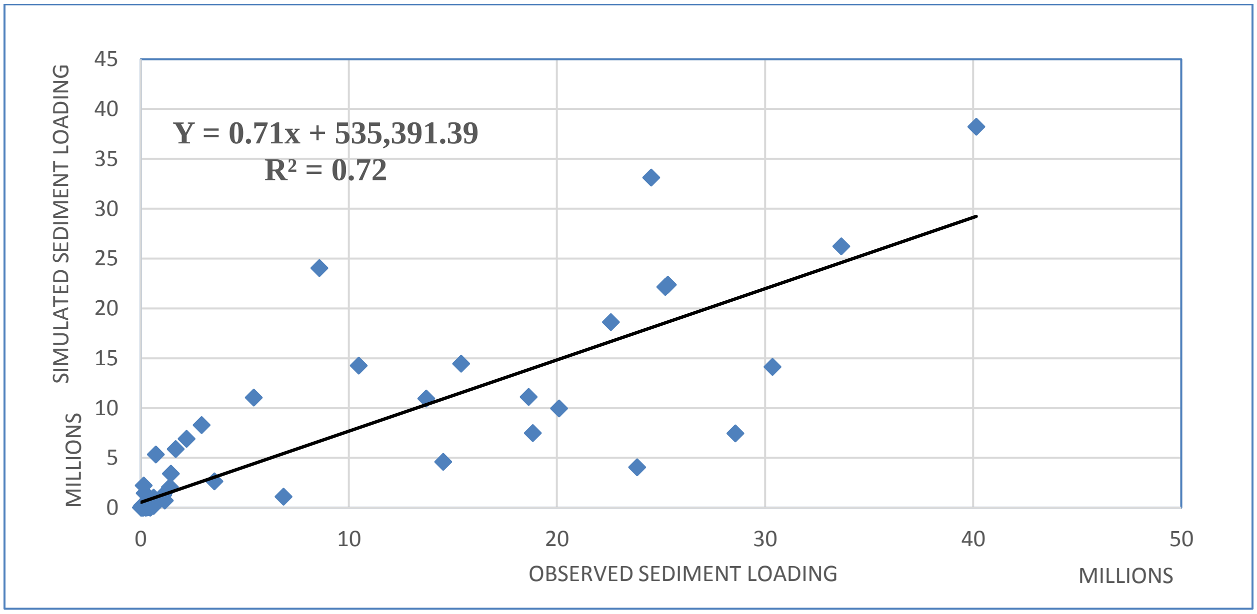



Figure 4.19. Regression analysis of simulated versus observed sediment load during validation period (2008-2014) for 2013 LULC

## 4.3 Spatial mapping and identification of sediment source areas

Once the model (SWAT) was calibrated and validated, it was run for a period 25 years (1990 to 2014), then the overall simulated output can be used for further application (the catchment can be represented for any hydrologic response) and sediment source areas were identified Watershed.

SWAT estimated the stream flow and sediment yield from the watershed to the reservoir for both 1990 and 2013 LULC maps. Therefore, 45.05 m3/s of stream flow and 57.06 Mtone annual sediment load was entered to the reservoir during 1990 and 66.56 m3/s of stream flow and 47.36 Mtone annual sediment load was entered to the reservoir during 2013 LULC land use/cover data. Then it shows that there is an increase of 47% and decrement of 17% of stream flow and sediment yield respectively. The increase in the stream flow and high soil rate in the catchment can attribute to urbanization, high rainfall intensity, poor land cover and shallow soil depth even if the sediment yield shows decrement, thus erosion is affected by changes in rain fall and cover than runoff. For instant if a farmer react to climate change by implementing different crop, crop varieties or even changes land use pattern, the erosion and deposition rate and pattern with in the catchment may change completely and therefor, net soil loss will change as well. This also holds true if cross drainage structures, retaining walls are developed with expansion of urbanization. The SWAT model also had 75 capability to identify areas within a watershed with high erosion and sediment yield. This helps to prioterize and formulate development and conservation plans in order to use available economic resource optimally. Since the erosion process occurred in the watershed is believed to be the major source of sediment load, it is important to give due attention for appropriate watershed development or soil and water conservation at least for those places which are major cause for higher sediment yield.

33 sub basins are classified as per the model (Figure 4.15). The default threshold cell area was taken when streams are defined, these might be the reason for which some of the sub basins have a very small areal coverage and areal coverage of the sub basins vary from 0 to 9.61 %. The largest coverage was occupied by sub basins 2, 9, 13, 24, 28 and 32 with 6.71, 5.51, 9.61, 6.72, 6.8 and 7.6 % coverage.

The model simulation of sediment yield varies from HRU to HRU. Sub basins having sediment yield above 12 ton/ha/year were selected as high to medium range sediment source areas of the watershed as shown in Figure 4.16 and their dominant HRU distribution (slope, soil and land use) were presented as shown in Table 4.14 below. The identification of dominant HRU distribution of high sediment source areas of the watershed is important for simplifying work in undertaking management options.

Table 4.18 Selected sub basins HRU distribution in watershed

| Sub basins | Dominant land use | Dominant slope Range | Dominant soil |
|---|---|---|---|
| 1,2,3,4,5,9,10,11,13,16,17, 19,23,24,26,27,28 | AGRC | 0-4 | Chromic Vertisols |
| 6 | AGRC | 7-14 | Calcic Xerosols |
| 7 | AGRC | 0-4 | Chromic Vertisols |
| 12,18,20 | AGRC | 7-14 | Chromic Vertisols |

The 25 year measured stream flow at Hombole station was found 43.69 $m^3$/s and the simulated stream flow by SWAT model is 66.56 $m^3$/s and measured annual sediment yield generated from rating curve at main Hombole gauging station was found 57.58 ton/ha/year and the simulated sediment yield by SWAT model is 44.881 ton/ha/year.

From (Preksedis Marco Ndomba and Ann van Griensven, 2011) , the mean annual sediment yield from Upper Awash basin is 60 ton/ha/year – 200 ton/ha /year. The result obtained from this research has overestimate the result found from this study. Land use /land cover was found the influential parameters for sediment yield rather than the existing surface runoff and precipitation.

As the study conducted by (Hurin, H., 1985) soil formation rates for erosion in different agro ecological zone of Ethiopia have range of 2 to 18 ton/ha/year tolerable soil loss levels. Out of the 33 sub basin created by the model, twenty three of the sub basins have sediment yield above 12 ton/ha/year which indicate most of the area are in non-tolerable range.it covers 70 % of the sub basins. Some of the sub basins having high areal coverage have contributed low runoff & sediment yield and vice versa, this may arise due to the existing HRU in each sub basins has revealed different surface runoff contribution in respective with the soil properties and land use effect that have on surface runoff generation.

The highest sediment yield sub basin areas are those that are covered with cultivated (dominantly & moderately cultivated) and Chromic Vertisols with small coverage of chromic Cambisols. The yellow and red highlighted areas of the watershed are potential areas which are susceptible for erosion and sediment yield.The HRU distribution for the selected sub basins clearly indicates the land cover (cultivated area) and forest land is the major controlling factor for sedimnet potential areas.

Sedimnet yield of a watershed is the summation of suspended and bed load. The analyiss described above is suspended sedimnet load. Suspended load is the portion of the sediment that is carried by a fluid flow which settle slowly enough such that it almost never touches the bed. Whereas Bed load consists of sediments that are moving along in a river bottom, or just above the bottom, essentially by either rolling or "saltation," where particles bounce along the bottom. These heavier particles are usually sands and gravels. From the total sediment contribution bed load contibutes 10 to 15% of suspended load.

Taking 12.5 % contiribution of bedload, the total mean annual measured and simulated sediment loading from the Upper Awash basin is 64.78 and 50.49 ton/ha/yr respectively.

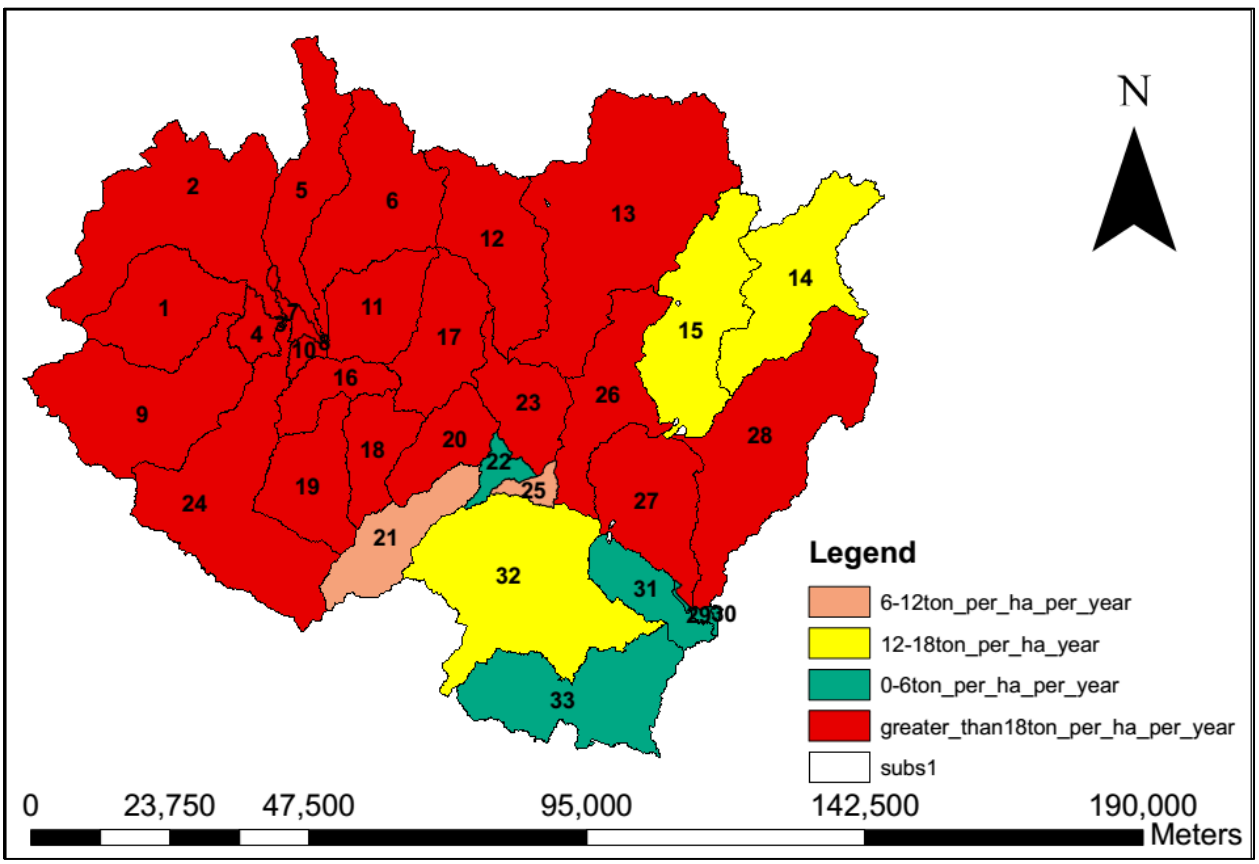



Figure 4.20. Spatial Distribution of annual average sediment yield contribution from sub basins of Upper awash watershed

## 4.4 Assessment of land use/cover change on stream flow and sediment yield

Several factors influence surface runoff ,soil erosion and sedimentation which include climate, soil, topography' and vegetation and management practices. Among this land use/land cover change is the one having an obvious impact on runoff sedimentation. As already mentioned two land use/land cover (1990 and 2013) data were used for analysis. The analysis of land LULC shows that there was significant change in the period between 1990 and 2013. The result has revealed that the dominant land use/land cover of 1990 land use map were cultivation land (82.92%), Natural forest (8.85%), grassland (3.33%), wetland (1.25%), urban (1.54%) and shrub land (1.46%) as indicated in (Figure: 4.19). However, it does not mean that the land use/land cover type of the watershed for 1990 LULC map were above mentioned land use types, rather plantation land and water were also found. While SWAT analyses and define HRUs threshold value of the watershed (i.e. land use percentage (%) over sub basin area was 20%, soil class percentage over land use area was 10% and slope class percentage over soil area was given as 20%) was ignored small percentage of LULC types.

It was also shown that the dominant land use/land cover types of 2013 land use map were cultivation land (62.27%), shrub land (10.48%), plantation (9.57%), Natural forest (5.99%), grassland (5.27%) and urban (3.67%). It is also observed the highly dominant land use type for both land use/land cover maps is cultivation land.

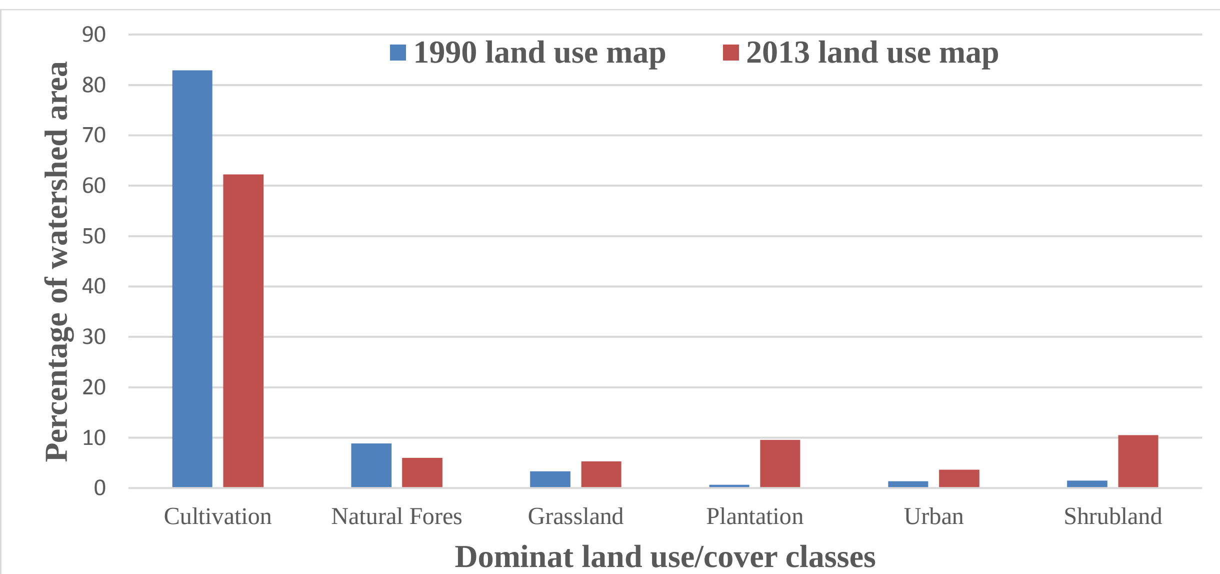



Figure 4.21. Land use/land cover distribution in each land use map

It is clearly shown that there is a significant change of LULC from 1990 land use map to 2013 land use map. The cultivation land and forest land for 1990 LULC map were 82.92% and 8.85, both decreased by 33.16% and 47.78% become 62.27% and 5.99% for 2013 LULC map. Nevertheless, urban was increased by 166% from 1990 to 2013. Plantation land increased from 0.63% (1990 LULC map) to 9.57% (2013 LULC map) also Grassland increased by 58.26% when going from 1990 to 2013 LULC map.

### 4.4.1 Change analysis on Surface runoff

The Arc SWAT is used to drive surface runoff for the entire watershed. The land use/land cover data of 1990 and 2013 LULC maps were used to compare surface runoff from the watershed. Therefore, it is very important to compare surface runoff from each sub basins. SWAT classified the watershed in to 33 sub basins, but it is very difficult to compare all sub basins. Some of the sub basins were selected based on the following criteria's:

- About 10 of sub basins were selected based on the higher amount of surface runoff. These sub basins were sub basin 3, 7, 9, 10, 11, 16, 17, 18, 19 and 24.
- About 5 of sub basins were selected based on the lower amount of surface runoff simulated. These sub basins were sub basin 21, 22, 29, 30 and 31.
- The last criteria were based on the varied land use/land cover found in the sub basin. It is well known that the increase in urban area will result in the increase in surface runoff. Based on this criteria sub basin 2, 6, 11, 12 and 13 were selected.

Based on the first criterion shown above, the result shows that there is an increase in surface runoff in all selected sub basins (Table 4.18 and figure 4.20). This was due to an increase in urbanization and woodland, and decrease in Natural forest. Even though there is decrease in cultivation land (M.A. Nearing et., al, 2005) stated that erosion and runoff will change more for each percent change in rain fall amount and intensity of storm than to each percent change in either canopy or ground cover.

Table 4.19 Mean annual surface run off in selected sub basin for 1990 and 2013 LULC map

| Sub basins | Area(ha) | Percentage of watershed area (%) | Mean annual for 1990 LULC (mm) | Mean annual surface runoff for 2013 LULC (mm) | Change in percentage (%) |
|---|---|---|---|---|---|
| #3 | 139.38 | 0.01 | 244.50676 | 360.85692 | 47.59 |
| #7 | 3255.2 | 0.31 | 237.7234 | 355.49116 | 49.54 |

| | | | | | |
|---|---|---|---|---|---|
| #9 | 58179 | 5.51 | 239.46596 | 395.24356 | 65.05 |
| #10 | 2854.9 | 0.27 | 241.2986 | 358.32 | 48.50 |
| #11 | 26231 | 2.49 | 183.07116 | 321.27708 | 75.49 |
| #16 | 14805 | 1.40 | 227.993 | 366.85092 | 60.90 |
| #17 | 29868 | 2.83 | 182.20124 | 343.82584 | 88.71 |
| #18 | 18780 | 1.78 | 239.01248 | 357.19436 | 49.45 |
| #19 | 28185 | 2.67 | 240.17864 | 404.29524 | 68.33 |
| #24 | 70885 | 6.72 | 238.8792 | 395.76624 | 65.68 |

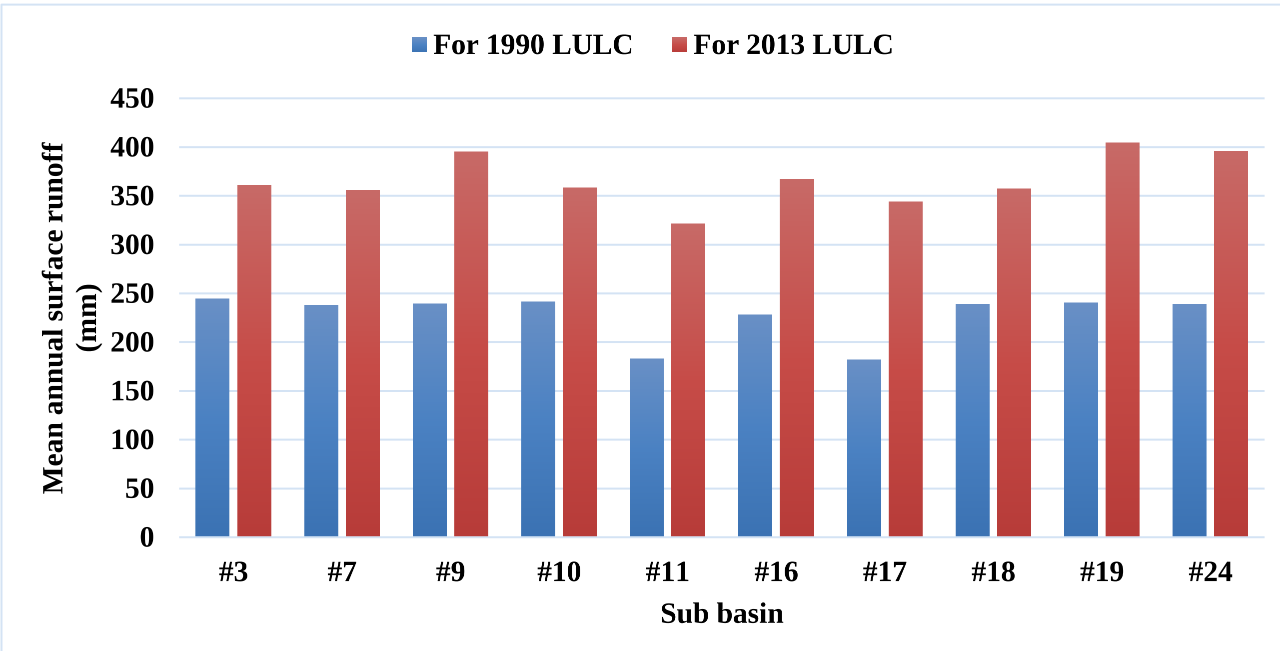



Figure 4.22 Mean annual surface runoff for selected sub basins

Based on the second criterion those sub basins having lower surface runoff has made change in runoff. Sub basins 21 and 22 are showing decrease in surface runoff from 1990 to 2013 LULC sub basins 29, 30 and 31 showing an increase in surface runoff (Table 4.19. and Figure 4.21). The decrease in surface runoff for the two-sub basin are the increment of plantation land and forestland. Cultivation land for sub basin 21 which was 100% during 1990 LULC map is reduced by 46% during 2013 LULC map and become 52.78% while remaining sub basin area is covered with Natural forest (15%) and (32.48%) plantation. In case of sub basin 22 cultivation land decrease by 21% from 100% cultivation land during 1990 LULC to 71% during 2013 LULC while the remaining sub basin area is covered by shrub land (6.85%), plantation (15.52%) and natural forestland (8.13%).The stream flow in sub basin 29 and 30 highly increase due to bare soil expansion in that sub basin.

Table 4.20 Mean annual surface run off in selected sub basin for 1990 and 2013 LULC map

| Sub basins | Area(ha) | Percentage of watershed area (%) | Mean annual surface runoff for 1990 LULC (mm) | Mean annual surface runoff for 2013 LULC (mm) | Change in percentage (%) |
|---|---|---|---|---|---|
| #21 | 25103 | 2.38 | 21.7796 | 16.9402 | -22.22 |
| #22 | 5513 | 0.52 | 7.38048 | 7.30208 | -1.06 |
| #29 | 1532.4 | 0.15 | 1.81488 | 3.94648 | 117.45 |
| #30 | 286.6 | 0.03 | 2.07404 | 4.51404 | 117.64 |
| #31 | 17122 | 1.62 | 15.733 | 16.38596 | 4.15 |

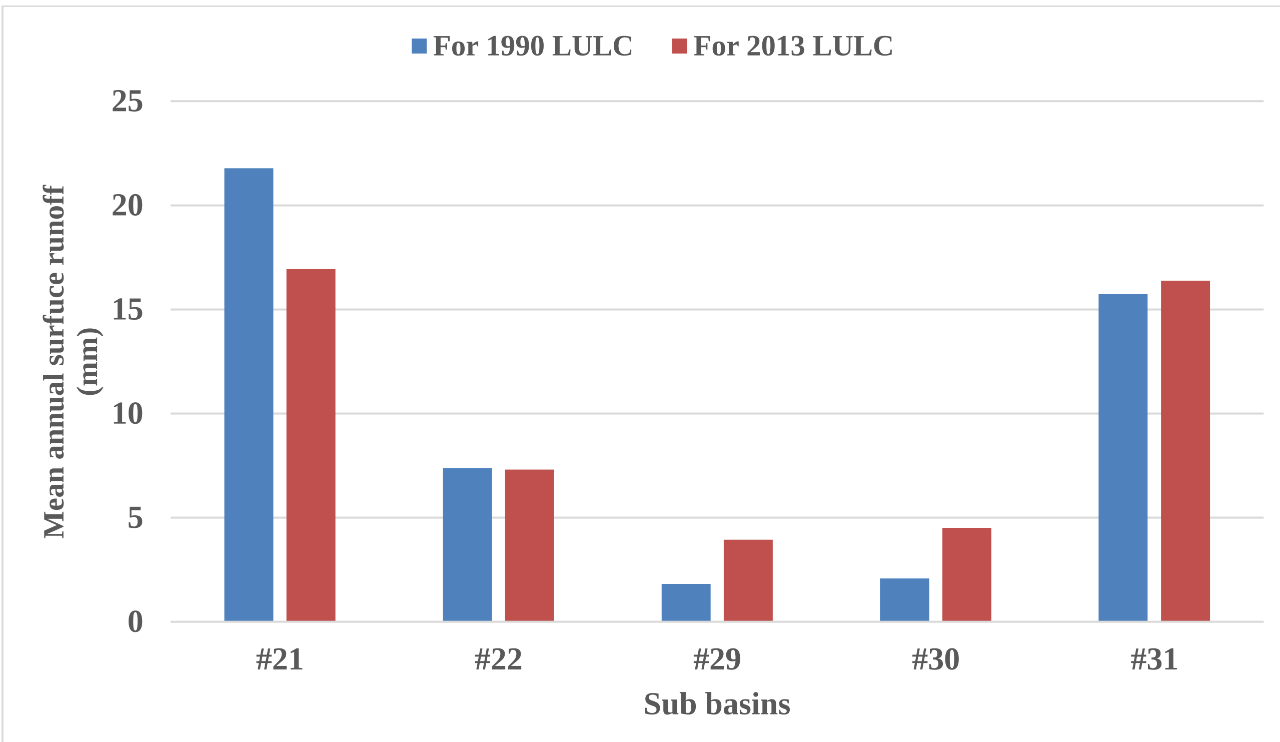



Figure 4.23 Mean annual surface runoff for selected sub basins

Based on the last criteria surface runoff was compared for different sub basins having varied dominant land use/land cover type. The sub basin selected were 2, 6, 11, 12 and 13. In these sub basins, the dominant land types are cultivation, grassland and natural forest for 1990 LULC map and cultivation, grassland, plantation and urban land for 2013 LULC (Figure 4.24 and Figure 4.25).

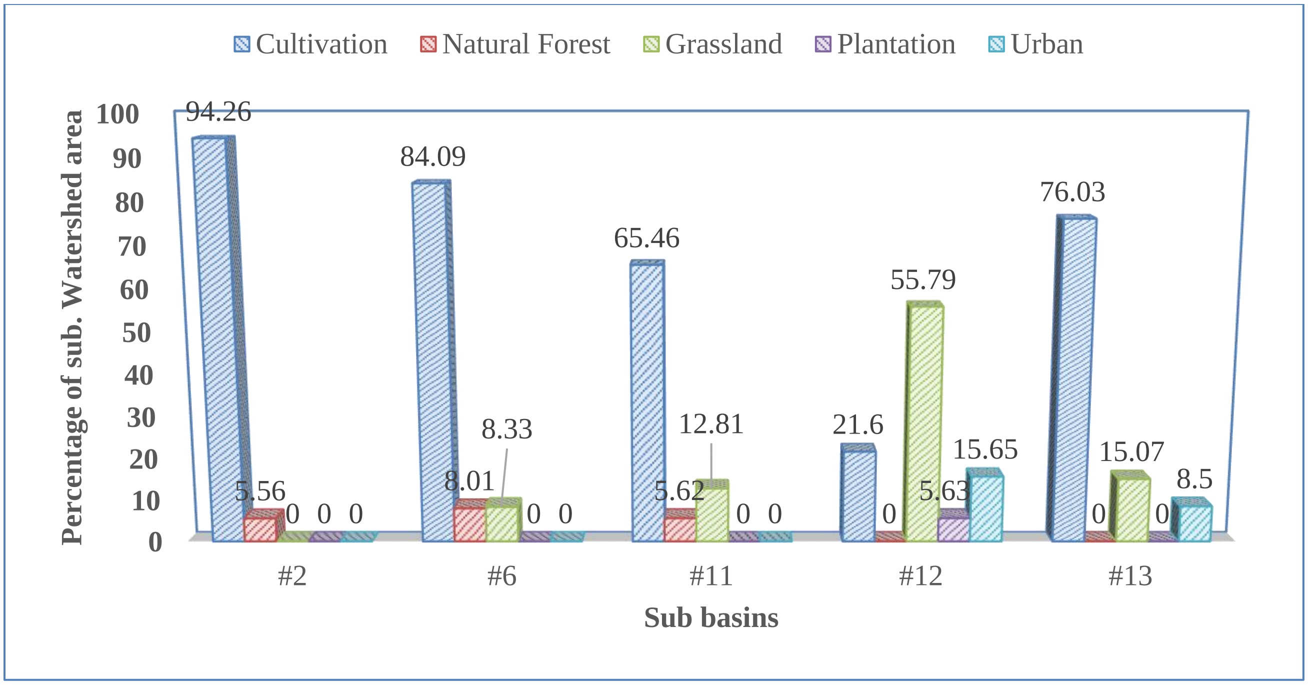



Figure 4.24 Dominant land use distribution in selected sub basin for 1990 LULC map

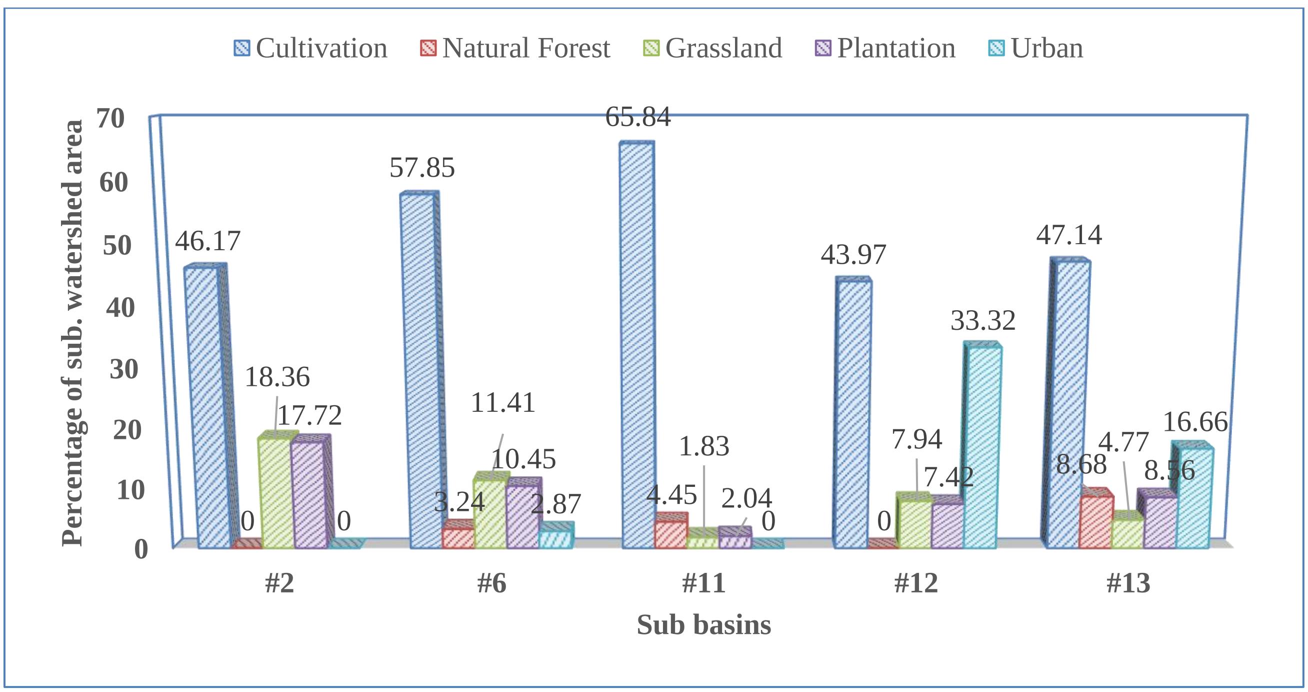



Figure 4.25 Dominant land use distribution in selected sub basin for 2013 LULC map

For sub basin 2, 6 and 11 Natural forestland decreased by 100%, 60% and 20% when going from 1990 to 2013 LULC respectively. This increment in land use is the main reason for the increase in surface runoff while, in sub basin 12 and 13 the increase in urban land by

53% and 49% going from 1990 to 2013 LULC highly contribute for the increase in surface runoff.

Table 4.21 Mean annual surface run off in selected sub basin for 1990 and 2013 LULC map

| Sub basins | Area(ha) | Percentage of watershed area (%) | Mean annual surface runoff for 1990 LULC (mm) | Mean annual surface runoff for 2013 LULC (mm) | Change in percentage (%) |
|---|---|---|---|---|---|
| #2 | 70831 | 6.71 | 144.07388 | 237.44488 | 64.81 |
| #6 | 48631 | 4.61 | 68.72472 | 102.3308 | 48.90 |
| #11 | 26231 | 2.49 | 183.07116 | 321.27708 | 75.49 |
| #12 | 41021 | 3.89 | 67.79424 | 170.54448 | 151.56 |
| #13 | 101450 | 9.61 | 203.6976 | 320.2704 | 57.23 |

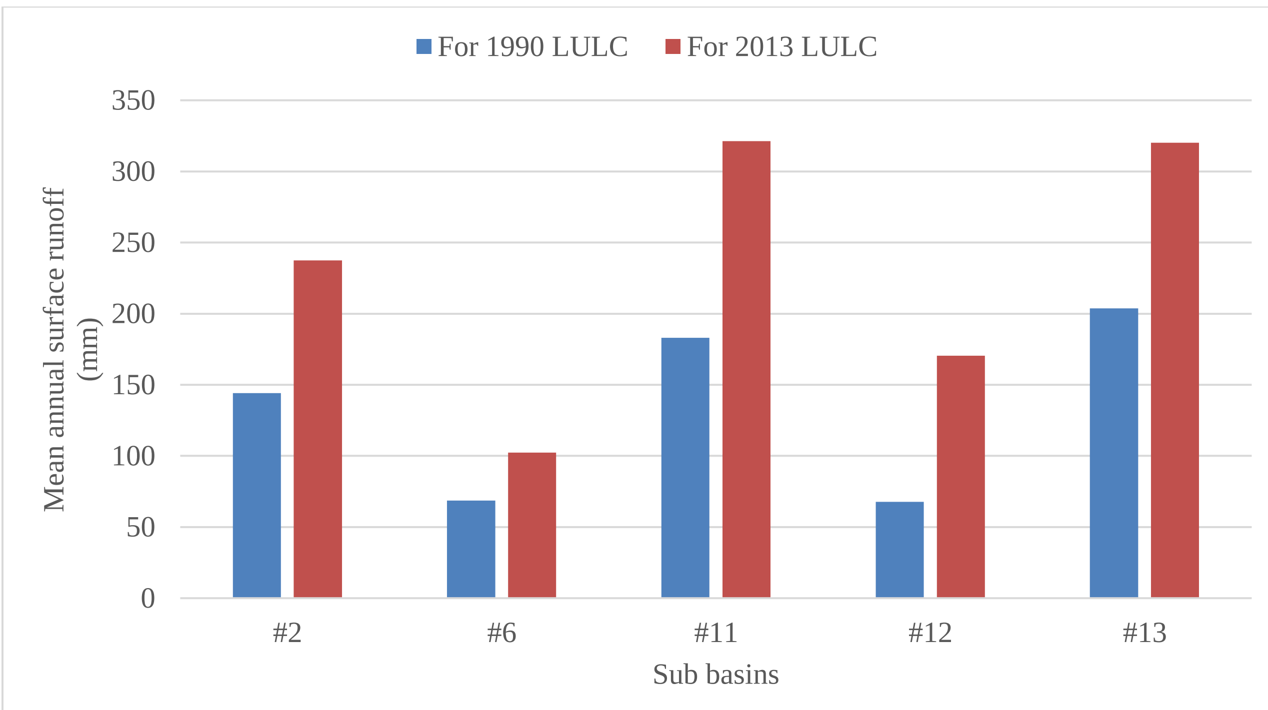



Figure 4.26 Mean annual surface runoff for selected sub basins

### 4.4.2 Change analysis on sediment yield

Based on the same criteria's used during stream flow analysis the above sub basin are selected. For the first criteria, selecting sub basins, which have high sediment yield. Sub basins 1, 2, 9, 11, 13, 16, 17, 18, 19 and 24 were selected. The detailed land use/land cover distribution, slope and soil type is found in the Appendix 9 and 12.Sub basin 22, 29, 30, 31 and 33, are selected based on sub basins having lower sediment yield. The detailed land use/land cover distribution, slope and soil type is found in the appendix 10 and 13. Sub basin 4, 6, 7, 10 and 13 were selected based on the varied land use/land cover found in the sub basin is found in the Appendix 11and 14.

Based on the first criterion, the result shows that there is decrease in all selected sub basins (Table 4.22 and Figure 4.27). This was due to the decrease in cultivation land and the increase in grassland, shrub land and plantation. Forestland increment in some sub basin also plays a vital role on sediment yield decrement. Erosion is affected by runoff amount as well as directly by rainfall energy and cover thus, the overall response to rainfall and cover change will be greater for erosion than the runoff amount. And erosion is likely to be more affected by change in rainfall and cover than runoff, though both are likely impacted in similar ways (M.A. Nearing et., al, 2005).

Table 4.22 Mean annual sediment yield in selected sub basin for 1990 and 2013 LULC map

| Sub basins | Area(ha) | Percentage of watershed area (%) | Mean annual sed. Yield for 1990 LULC (ton/ha) | Mean annual sed. Yield for 2013 LULC (ton/ha) | Change in percentage (%) |
|---|---|---|---|---|---|
| #1 | 34610 | 3.28 | 57.15848 | 38.50652 | -32.63 |
| #2 | 70831 | 6.71 | 67.45972 | 54.06912 | -19.85 |
| #9 | 58179 | 5.51 | 118.70108 | 82.92 | -30.14 |
| #11 | 26231 | 2.49 | 50.27488 | 45.9292 | -8.64 |
| #13 | 101450 | 9.61 | 97.71804 | 79.35728 | -18.79 |
| #16 | 14805 | 1.40 | 54.83676 | 45.72356 | -16.62 |
| #17 | 29868 | 2.83 | 90.12824 | 87.5498 | -2.86 |
| #18 | 18780 | 1.78 | 132.0548 | 100.5846 | -23.83 |
| #19 | 28185 | 2.67 | 120.10188 | 102.76004 | -14.44 |
| #24 | 70885 | 6.72 | 128.00424 | 103.23108 | -19.35 |

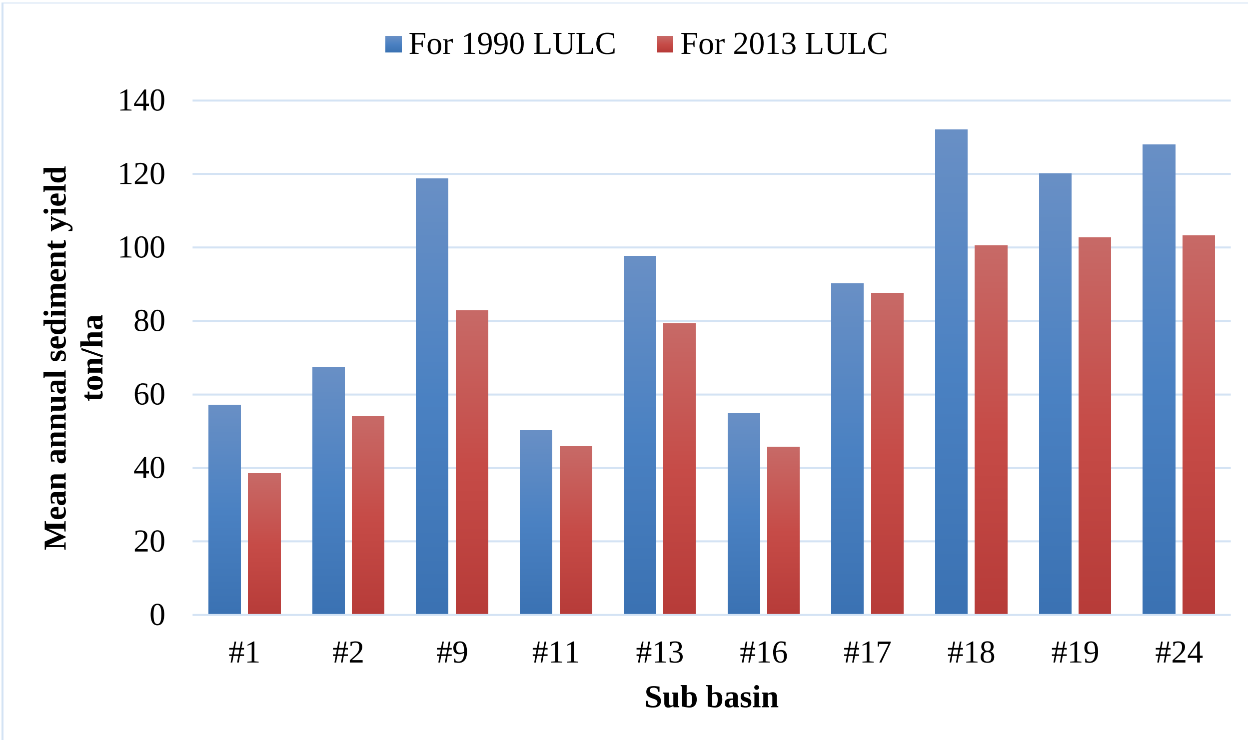



Figure 4.27 Mean annual sediment yield for selected sub basins

Based on the second criterion those sub basins having lower sediment yield has made change in sediment yield. Sub basins 22, 31 and 33 are showing decrease in sediment yield from 1990 to 2010 LULC while sub basins 29 and 30 showing an increase in sediment yield (Table 4.23. and Figure 4.28). The reason for an increase in sediment yield is due the decrease in wetland and water for basin 29 and the expansion of woodland and bare soil in sub basin 30 when going from 1990 to 2013 LULC.

Table 4.23 Mean annual sediment yield in selected sub basin for 1990 and 2013 LULC map

| Sub basins | Area(ha) | Percentage of watershed area (%) | Mean annual sed. Yield for 1990 LULC (ton/ha) | Mean annual sed. Yield for 2013 LULC (ton/ha) | Change in percentage (%) |
|---|---|---|---|---|---|
| #22 | 5513 | 0.52 | 3.31112 | 1.69464 | -48.82 |
| #29 | 1532.4 | 0.15 | 0.0654 | 0.12576 | 92.29 |
| #30 | 286.6 | 0.03 | 0.07788 | 0.10808 | 38.78 |
| #31 | 17122 | 1.62 | 1.4512 | 0.76256 | -47.45 |
| #33 | 48278 | 4.57 | 3.44192 | 1.78296 | -48.20 |

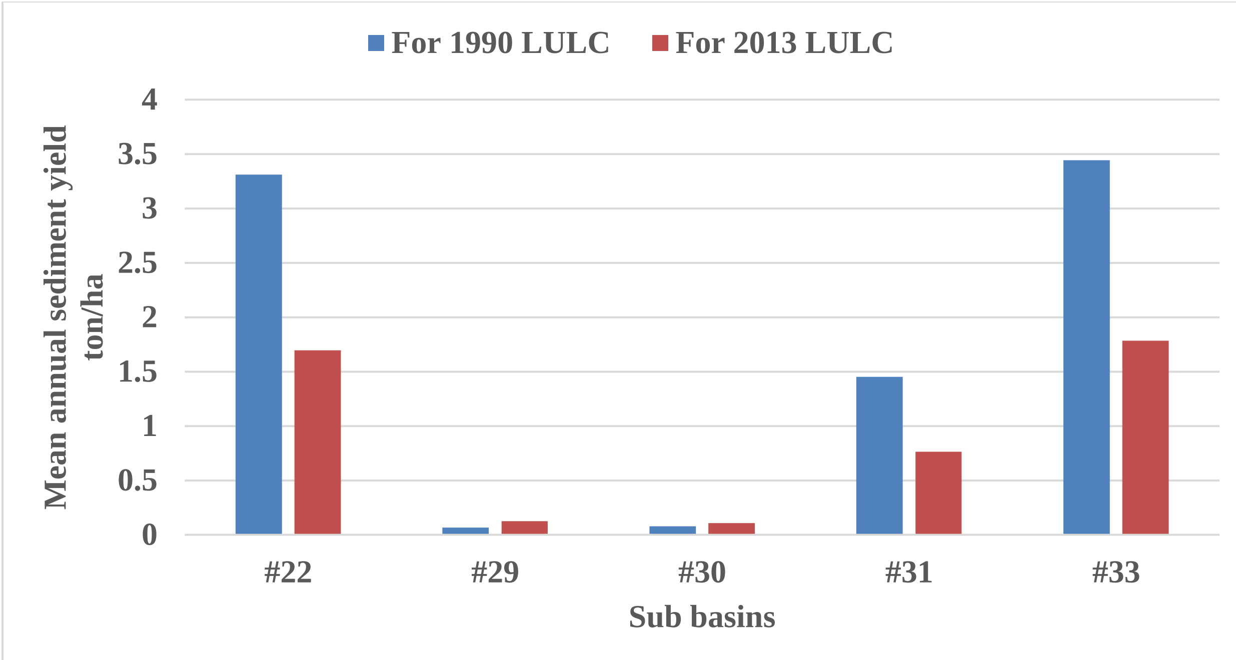



Figure 4.28 Mean annual sediment yield for selected sub basins

Based on the last criteria sediment yield was compared for different sub basins having varied dominant land use/land cover type. The sub basin selected were 2, 6, 11, 12 and 13. In these sub basins, the dominant land types are cultivation, grassland and natural forest for 1990 LULC map and cultivation, grassland, plantation and urban land for 2013 LULC (Figure 4.24 and Figure 4.25).

The increase in sediment yield in sub basin 12 is mainly due to the increase in cultivation land and urban by 51% and 53 %, and the decrease in grassland by 86.22% when going from 1990 to 2013 LULC respectively.

Table 4.24 Mean annual sediment yield in selected sub basin for 1990 and 2013 LULC map

| Sub basins | Area(ha) | Percentage of watershed area (%) | Mean annual sed. Yield for 1990 LULC (t/ha) | Mean annual sed. Yield for 2013 LULC (t/ha) | Change in percentage (%) |
|---|---|---|---|---|---|
| #2 | 70831 | 6.71 | 67.45972 | 54.06912 | -19.85 |
| #6 | 48631 | 4.61 | 29.33472 | 22.36384 | -23.76 |
| #11 | 26231 | 2.49 | 50.27488 | 45.9292 | -8.64 |
| #12 | 41021 | 3.89 | 25.486 | 39.46152 | 54.84 |
| #13 | 101450 | 9.61 | 97.71804 | 79.35728 | -18.79 |

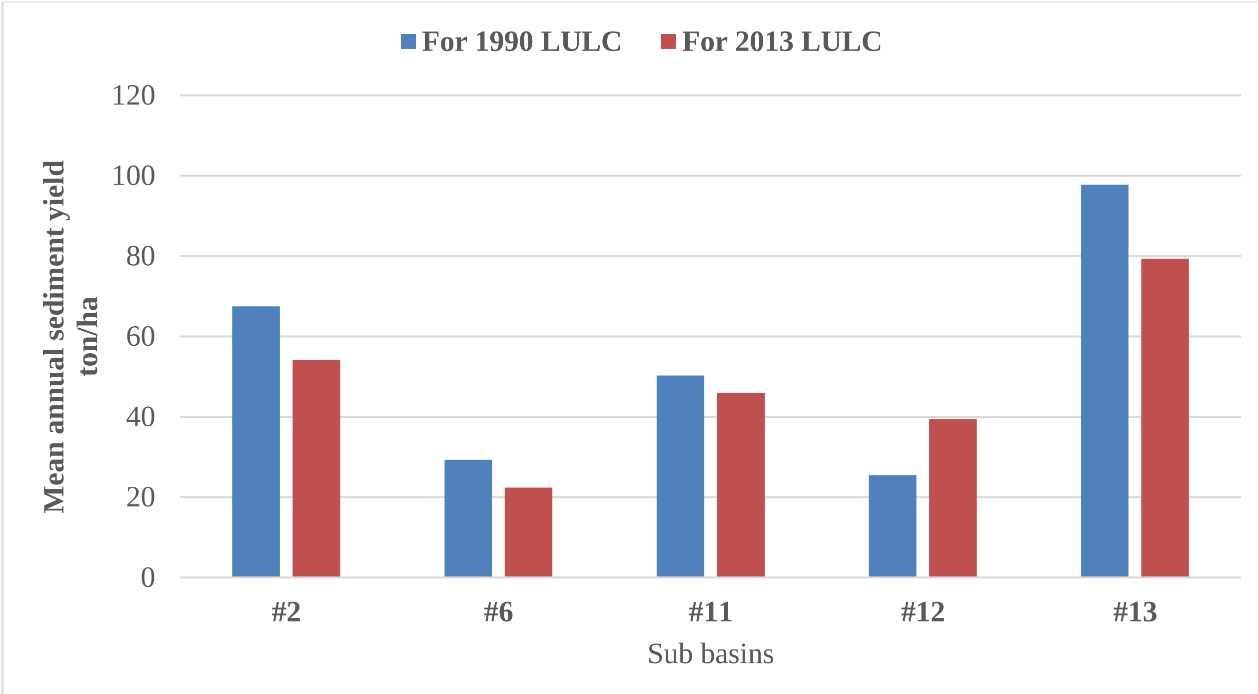



Figure 4.29 Mean annual sediment yield for selected sub basins

# CHAPTER FIVE

# 5 CONCLUSION AND RECOMMENRDATION

## 5.1 Conclusion

The SWAT model was found to be useful in identifying effect of land use changes on hydrological properties and sediment yield. SWAT model performance in upper awash basin was very good in in predicting stream flow and sediment yield despite scarce data of observed suspended sediment load.

As it looked from the model performance efficiency indicators, regression coefficient ($R^2$), the Nash-Sutcliffe (NSE), Root mean square error observation standard deviation ratio (RSR) and percentage of bias (PBIAS) are found to be 0.83, 0.78, 0.22 and -23.78% respectively in calibration and 0.81, 0.78, 0.22 and -20.84% respectively in validation for flow analysis. Similarly, sediment model efficiency $R^2$, NSE, RSR and PBIAS are found to be 0.81, 0.78, 0.22 and 15.72 for calibration and 0.72, 0.72, 0.28 and 17.62% in validation respectively. This shows the SWAT model simulate well stream flow and sediment yield/load in upper awash basin.

Simulation result indicates that land use/cover change has a great impact on reservoir sedimentation. To analyze the impact of land use change on sediment yield different comparison criteria were applied. The first was selecting sub basins having higher surface runoff and sediment yield and found around the main course of the river and the second was selecting and analyzing sub basins having lower surface runoff and sediment yield and the third criterion was based on availability of varied land use class. While analyzing the impact of land use/cover in all criteria using 1990 and 2013 land use/cover map. It shows an increase in stream flow and decrease in sediment yield.

SWAT estimated the stream flow and sediment yield from the watershed to the reservoir for both 1990 and 2013 LULC maps. Therefore, 45.05 m3/s of stream flow and 57.06 Mtone annual sediment load was entered to the reservoir during 1990 and 66.56 m3/s of stream flow and 47.36 Mtone annual sediment load was entered to the reservoir during 2013 LULC land use/cover data. Then it shows that there is an increase of 47% and decrement of 17% of stream flow and sediment yield respectively. The increase in the stream flow and high soil rate in the catchment can attribute to urbanization, high rainfall intensity, poor land cover and shallow soil depth even if the sediment yield shows decrement, thus erosion is affected by changes in rain fall and cover than runoff. For instant if a farmer react to climate change by implementing different crop, crop varieties or even changes land use pattern, the erosion and deposition rate and pattern with in the catchment may change completely and therefor, net soil loss will change as well. This also holds true if cross drainage structures, retaining walls are developed with expansion of urbanization. The SWAT model also had 75 capability to identify areas within a watershed with high erosion and sediment yield. This helps to prioterize and formulate development and conservation plans in order to use available economic resource optimally. Since the erosion process occurred in the watershed is believed to be the major source of sediment load, it is important to give due attention for appropriate watershed development or soil and water conservation at least for those places which are major cause for higher sediment yield.

### 5.2 Recommendation

The following points are recommendations, which have to be addressed well while analyzing such kind of research in the feature:-

- This research analyses land use/cover impact on surface runoff and sedimentation, but further research shall be done on extreme flow, water yield …etc.
- This research was taking in to account the dominant land use/cover feature of the watershed, but better result could be obtained if the detailed land use/cover data of watershed was considered. Two land use/cover maps were used for comparison, if more map were used it is easy to identify the change.

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## APPENDIX

### Appendix 1: Definition of weather generator parameters

| *parameter* | ***Definition*** |
|---|---|
| **TMPMX** | Average or Mean maximum air temperature for month ($^0$C) |
| **TMPMN** | Average or Mean minimum air temperature for month ($^0$C) |
| **TMPSTMX** | Standard deviation for daily maximum temperature for month ($^0$C) |
| **TMPSTDMN** | Standard deviation for daily maximum temperature for month($^0$C |
| **PCPMM** | Average or Mean total monthly precipitation(mm $H_2o$) |
| **PCPSTD** | Standard Deviation for daily precipitation in month (mm $H_2o$) |
| **PCPSKW** | Skew Coeffiecnt For daily Precipitation in month |
| **PR_W(1)** | PR_W1 Probability of a wet following a dry day in the month |
| **PR_W(2)** | PR_W2 Probability of a wet following a wet day in the month |
| **PCPD** | Average number of days of precipitation in month |
| **SOLARAV** | Average daily solar radiation for month (MJ/m$^2$/day) |
| **RAINHHMX** | Average maximum half hour rainfall(mm) |
| **DEWPT** | Average daily dew point temperature ($^0$C) |
| **WINDAV** | Average daily Wind Speed in month(m/s) |

### Appendix 2: Definition of soil parameters

| **Code** | **Description** |
|---|---|
| **SNAM** | Soil Name |
| **NLAYERS** | No of layers |
| **HYDGRP** | Soil Hydrologic Group(A,B,C,D) |
| **SOL_ZMX** | Maximum Rooting Depth of the soil profile |
| **TEXTURE** | Soil texture |
| **SOL_Z** | Depth from soil surface to bottom layer |
| **SOL_BD** | Moist bulk density for soil |
| **SOL_AWC** | Available Water Capacity Of soil Layer |
| **SOL_K** | saturated Hydraulic conductivity |
| **SOL_CBN** | Organic Carbon Content |
| **CLAY** | Clay Content |
| **SILT** | Silt Content |
| **SAND** | Sand Content |
| **ROCK** | Rock Fragment Content |
| **SOL_ALB** | Moist Soil Albedo |
| **USLE_K** | Soil Erodiblity(K factor) |

**Appendix 3:** **Weather generator Statistics for Addisababa bole Station**

| Parameters | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TMPMX** | 32.82 | 34.77 | 35.91 | 36.02 | 33.28 | 28.17 | 26.56 | 26.61 | 28.08 | 29.36 | 31.01 | 32.11 |
| **TMPMN** | 11.44 | 13.91 | 16.34 | 18.08 | 18.06 | 18.02 | 17.20 | 17.00 | 16.58 | 15.86 | 13.31 | 11.47 |
| **TMPSTMX** | 3.09 | 3.30 | 3.25 | 3.38 | 3.61 | 5.10 | 2.56 | 2.40 | 2.42 | 2.51 | 2.55 | 2.67 |
| **TMPSTDMN** | 3.04 | 3.27 | 3.75 | 3.70 | 2.92 | 3.50 | 2.21 | 2.22 | 2.45 | 2.96 | 2.73 | 2.71 |
| **PCPMM** | 1.18 | 1.51 | 8.07 | 29.76 | 114.24 | 283.44 | 369.39 | 408.38 | 254.05 | 129.43 | 20.21 | 3.30 |
| **PCPSTD** | 0.44 | 0.54 | 1.70 | 3.53 | 7.65 | 11.23 | 14.06 | 15.89 | 11.60 | 7.97 | 3.20 | 0.77 |
| **PCPSKW** | 17.07 | 16.98 | 10.43 | 5.74 | 3.22 | 2.34 | 2.04 | 2.89 | 2.80 | 3.31 | 8.44 | 11.37 |
| **PR_W(1)** | 0.02 | 0.02 | 0.06 | 0.14 | 0.31 | 0.72 | 0.86 | 0.83 | 0.71 | 0.26 | 0.08 | 0.03 |
| **PR_W(2)** | 0.13 | 0.50 | 0.49 | 0.56 | 0.69 | 0.86 | 0.92 | 0.92 | 0.85 | 0.76 | 0.53 | 0.39 |
| **PCPD** | 0.80 | 1.20 | 2.95 | 6.80 | 14.70 | 25.35 | 28.20 | 28.60 | 24.90 | 17.05 | 5.15 | 1.55 |
| **SOLARAV** | 21.27 | 22.09 | 22.80 | 23.57 | 21.54 | 18.27 | 16.39 | 17.47 | 19.20 | 20.66 | 21.29 | 20.91 |
| **DEWPT** | 9.91 | 9.87 | 11.02 | 12.02 | 11.89 | 11.96 | 11.78 | 11.88 | 11.34 | 9.43 | 8.85 | 8.78 |
| **WINDAV** | 0.40 | 0.54 | 0.72 | 0.76 | 0.80 | 0.77 | 0.60 | 0.56 | 0.47 | 0.35 | 0.32 | 0.36 |

**Appendix 4:** **Weather generator Statistics for Debrezeyit Station**

| Parameters | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TMPMX** | 32.82 | 34.77 | 35.91 | 36.02 | 33.28 | 28.17 | 26.56 | 26.61 | 28.08 | 29.36 | 31.01 | 32.11 |
| **TMPMN** | 11.44 | 13.91 | 16.34 | 18.08 | 18.06 | 18.02 | 17.20 | 17.00 | 16.58 | 15.86 | 13.31 | 11.47 |
| **TMPSTMX** | 3.09 | 3.30 | 3.25 | 3.38 | 3.61 | 5.10 | 2.56 | 2.40 | 2.42 | 2.51 | 2.55 | 2.67 |
| **TMPSTDMN** | 3.04 | 3.27 | 3.75 | 3.70 | 2.92 | 3.50 | 2.21 | 2.22 | 2.45 | 2.96 | 2.73 | 2.71 |
| **PCPMM** | 1.18 | 1.51 | 8.07 | 29.76 | 114.24 | 283.44 | 369.39 | 408.38 | 254.05 | 129.43 | 20.21 | 3.30 |
| **PCPSTD** | 0.44 | 0.54 | 1.70 | 3.53 | 7.65 | 11.23 | 14.06 | 15.89 | 11.60 | 7.97 | 3.20 | 0.77 |
| **PCPSKW** | 17.07 | 16.98 | 10.43 | 5.74 | 3.22 | 2.34 | 2.04 | 2.89 | 2.80 | 3.31 | 8.44 | 11.37 |
| **PR_W(1)** | 0.02 | 0.02 | 0.06 | 0.14 | 0.31 | 0.72 | 0.86 | 0.83 | 0.71 | 0.26 | 0.08 | 0.03 |
| **PR_W(2)** | 0.13 | 0.50 | 0.49 | 0.56 | 0.69 | 0.86 | 0.92 | 0.92 | 0.85 | 0.76 | 0.53 | 0.39 |
| **PCPD** | 0.80 | 1.20 | 2.95 | 6.80 | 14.70 | 25.35 | 28.20 | 28.60 | 24.90 | 17.05 | 5.15 | 1.55 |
| **SOLARAV** | 21.27 | 22.09 | 22.80 | 23.57 | 21.54 | 18.27 | 16.39 | 17.47 | 19.20 | 20.66 | 21.29 | 20.91 |
| **DEWPT** | 10.61 | 11.91 | 11.39 | 12.05 | 12.96 | 11.80 | 11.93 | 13.62 | 14.33 | 13.43 | 10.12 | 9.76 |
| **WINDAV** | 0.40 | 0.54 | 0.72 | 0.76 | 0.80 | 0.77 | 0.60 | 0.56 | 0.47 | 0.35 | 0.32 | 0.36 |

**Appendix 5: <u>Measured Mean Monthly stream flow (m^3/s) at Hombole Gauging station</u>**

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 3.46 | 12.87 | 18.78 | 24.16 | 4.94 | 11.11 | 87.00 | 235.20 | 116.76 | 17.06 | 4.02 | 2.94 |
| 1991 | 2.77 | 5.07 | 9.13 | 2.72 | 2.52 | 10.41 | 98.42 | 256.19 | 153.69 | 9.58 | 3.63 | 3.29 |
| 1992 | 3.43 | 6.52 | 3.37 | 4.40 | 4.15 | 10.91 | 72.43 | 203.35 | 143.68 | 16.43 | 4.20 | 3.23 |
| 1993 | 2.92 | 4.89 | 2.50 | 10.28 | 12.13 | 27.87 | 124.45 | 265.14 | 191.18 | 31.79 | 8.01 | 4.06 |
| 1994 | 2.82 | 2.31 | 2.43 | 4.75 | 4.29 | 10.33 | 74.00 | 157.52 | 144.93 | 16.53 | 5.01 | 4.83 |
| 1995 | 4.26 | 4.52 | 3.09 | 14.90 | 5.49 | 10.69 | 72.23 | 190.23 | 75.44 | 7.76 | 3.28 | 2.86 |
| 1996 | 5.42 | 4.15 | 5.87 | 12.49 | 21.65 | 84.06 | 194.47 | 348.26 | 133.88 | 13.22 | 5.89 | 3.99 |
| 1997 | 4.04 | 3.22 | 2.97 | 5.50 | 4.11 | 15.69 | 57.71 | 119.28 | 32.38 | 10.03 | 10.68 | 6.10 |
| 1998 | 5.01 | 3.69 | 11.16 | 8.21 | 11.31 | 24.62 | 137.37 | 366.56 | 161.03 | 41.71 | 9.09 | 5.46 |
| 1999 | 4.98 | 4.10 | 4.58 | 3.44 | 3.56 | 20.80 | 110.43 | 269.34 | 62.90 | 47.58 | 8.64 | 5.12 |
| 2000 | 4.15 | 3.75 | 1.94 | 3.16 | 5.67 | 12.57 | 63.10 | 178.61 | 90.99 | 30.79 | 12.48 | 6.04 |
| 2001 | 0.88 | 0.71 | 4.17 | 1.76 | 3.92 | 26.36 | 103.35 | 143.07 | 54.08 | 3.76 | 1.93 | 1.11 |
| 2002 | 5.01 | 3.46 | 4.09 | 4.91 | 4.37 | 11.27 | 58.82 | 141.59 | 48.69 | 8.77 | 6.75 | 3.06 |
| 2003 | 2.86 | 2.48 | 4.07 | 9.55 | 5.89 | 22.03 | 117.64 | 180.98 | 102.17 | 14.92 | 8.03 | 5.20 |
| 2004 | 3.68 | 2.85 | 3.90 | 14.74 | 5.29 | 20.49 | 88.59 | 166.73 | 87.11 | 16.74 | 9.33 | 4.49 |
| 2005 | 5.13 | 3.79 | 10.43 | 7.71 | 30.29 | 26.01 | 124.39 | 192.58 | 94.34 | 18.21 | 11.14 | 5.63 |
| 2006 | 4.31 | 4.00 | 9.73 | 17.12 | 15.50 | 26.20 | 155.89 | 269.65 | 143.56 | 18.66 | 11.81 | 6.01 |
| 2007 | 5.00 | 5.47 | 5.15 | 8.22 | 11.83 | 39.81 | 127.92 | 253.47 | 158.64 | 25.10 | 11.11 | 7.49 |
| 2008 | 4.66 | 4.16 | 3.31 | 3.72 | 5.64 | 16.80 | 118.76 | 216.79 | 159.12 | 18.41 | 22.48 | 6.08 |
| 2009 | 9.51 | 4.25 | 3.44 | 9.52 | 5.31 | 7.42 | 45.25 | 185.45 | 111.66 | 25.89 | 6.16 | 6.77 |
| 2010 | 4.54 | 12.56 | 10.97 | 21.57 | 19.45 | 35.68 | 162.37 | 178.78 | 153.67 | 18.51 | 9.99 | 5.36 |
| 2011 | 4.83 | 3.96 | 5.43 | 3.78 | 11.23 | 27.06 | 68.99 | 202.57 | 126.23 | 21.68 | 9.78 | 5.78 |
| 2012 | 4.27 | 3.74 | 3.15 | 10.67 | 8.25 | 12.19 | 93.95 | 271.37 | 243.06 | 19.20 | 7.73 | 5.21 |
| 2013 | 4.22 | 3.39 | 6.42 | 13.63 | 11.81 | 31.92 | 93.58 | 169.78 | 137.59 | 40.52 | 12.16 | 4.98 |
| 2014 | 3.86 | 4.45 | 4.74 | 6.52 | 10.31 | 14.20 | 55.98 | 147.20 | 84.69 | 32.04 | 10.02 | 4.68 |

*Appendix 6:* **Redefined and original land covers for Upper awash watershed**

| Original Land Covers | Redefined land Cover According to SWAT | SWAT Code |
|---|---|---|
| Cultivation | Agricultural Land-Close-grown | AGRC |
| Natural Forest | Forest-Mixed | FRST |
| Woodland | Forest-Deciduous | FRSD |
| Afro_Alphine | Forest-Evergreen | FRSE |
| Plantation | Wetlands-Forested | WETF |
| Wetland | Wetlands-Non-Forested | WETN |
| Lava flow | Pasture | PAST |
| Grassland | Range-Grasses | RNGE |
| Shrub land | Range-Brush | RNGB |
| Bare soil | Southwestern US (Arid) Range | SWRN |
| Water | Water | WATR |
| Urban | Residential | URBN |

**Appendix 7: Areal coverage of Upper Awash Basin delineated by SWAT model**

| Sub Basin | Area (Km^2) | Areal coverage (%) | Sub Basin | Area (Km^2) | Areal coverage (%) | Sub Basin | Area (Km^2) | Areal coverage (%) |
|---|---|---|---|---|---|---|---|---|
| **1** | 346.10 | 3.28 | **12** | 410.21 | 3.89 | **23** | 231.72 | 2.20 |
| **2** | 708.31 | 6.71 | **13** | 1014.5 | 9.61 | **24** | 708.85 | 6.72 |
| **3** | 1.39 | 0.01 | **14** | 470.73 | 4.46 | **25** | 41.473 | 0.39 |
| **4** | 67.08 | 0.64 | **15** | 488.3 | 4.63 | **26** | 354.4 | 3.36 |
| **5** | 332.36 | 3.15 | **16** | 148.05 | 1.40 | **27** | 378.06 | 3.58 |
| **6** | 486.31 | 4.61 | **17** | 298.68 | 2.83 | **28** | 717.78 | 6.80 |
| **7** | 32.55 | 0.31 | **18** | 187.8 | 1.78 | **29** | 15.324 | 0.15 |
| **8** | 0.00 | 0.00 | **19** | 281.85 | 2.67 | **30** | 2.866 | 0.03 |
| **9** | 581.79 | 5.51 | **20** | 194.06 | 1.84 | **31** | 171.22 | 1.62 |
| **10** | 28.55 | 0.27 | **21** | 251.03 | 2.38 | **32** | 802.32 | 7.60 |
| **11** | 262.31 | 2.49 | **22** | 55.13 | 0.52 | **33** | 482.78 | 4.57 |

**Appendix: 8 Dominant land use/cover, slope and soil type of Upper Awash Basin**

| Sub basins | Dominant land use | Dominant slope Range | Dominant soil | Sub basins | Dominant land use | Dominant slope Range | Dominant soil |
|---|---|---|---|---|---|---|---|
| 1 | RNGE | 4-7 | Chromic Vertisols | 13 | FRST | 4-7 | Chromic Vertisols |
| | RNGB | 0-4 | Chromic Luvisols | | RNGB | 0-4 | Calcic Xerosols |
| | WETF | 7-14 | | | WETF | 7-14 | |
| | AGRC | | | | AGRC | | |
| 2 | RNGE | 7-14 | Calcic Xerosols | | URBN | | |
| | RNGB | 14-23 | Chromic Vertisols | 16 | FRST | 0-4 | Chromic Vertisols |
| | WETF | 23-999 | Leptosols | | RNGB | 4-7 | |
| | AGRC | 0-4 | | | AGRC | | |
| | | 4-7 | | 17 | FRST | 23-9999 | Chromic Cambisols |
| 3 | RNGB | 0-4 | Chromic Vertisols | | RNGB | 0-4 | Chromic Vertisols |
| | AGRC | 4-7 | | | AGRC | 4-7 | |
| 4 | RNGE | 4-7 | Chromic Vertisols | | | 14-23 | |
| | RNGB | 0-4 | Chromic Luvisols | 18 | RNGB | 7-14 | Chromic Vertisols |
| | WETF | | | | WETF | 4-7 | Dystric Nitosols |
| | AGRC | | | | AGRC | 0-4 | |
| 5 | RNGE | 0-4 | Calcic Xerosols | | | 14-23 | |
| | RNGB | 7-14 | Chromic Vertisols | | | 23-9999 | |
| | WETF | 4-7 | | 19 | FRST | 0-4 | Chromic Vertisols |
| | AGRC | 14-23 | | | RNGB | 4-7 | |
| | | 23-999 | | | WETF | 7-14 | |
| 6 | RNGE | 7-14 | Calcic Xerosols | | AGRC | | |
| | RNGB | 4-7 | Eutric Nitisols | 20 | FRST | 4-7 | Chromic Vertisols |
| | WETF | 0-4 | Chromic Vertisols | | RNGB | 0-4 | Orthic Solonchaks |
| | AGRC | | | | WETF | 7-14 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | FRSD | 0-4 | Chromic Vertisols | | AGRC | 14-23 | |
| | RNGB | 4-7 | | | | 23-9999 | |
| | WETF | | | 23 | FRST | 4-7 | Chromic Vertisols |
| | AGRC | | | | RNGB | 0-4 | |
| 9 | RNGE | 4-7 | Chromic Vertisols | | AGRC | 7-14 | |
| | RNGB | 7-14 | | 24 | FRST | 0-4 | Chromic Vertisols |
| | WETF | 0-4 | | | RNGB | 4-7 | |
| | AGRC | | | | WETF | 7-14 | |
| 10 | FRST | 4-7 | Chromic Vertisols | | AGRC | | |
| | RNGB | 0-4 | | 26 | FRST | 23-9999 | Chromic Cambisols |
| | WETF | | | | RNGB | 0-4 | Chromic Vertisols |
| | AGRC | | | | AGRC | 4-7 | |
| 11 | FRSE | 4-23 | chromic cambisols | | | 7-14 | |
| | FRSD | 23-9999 | Chromic Vertisols | 27 | RNGB | 0-4 | Chromic Vertisols |
| | RNGB | 4-7 | Luvic Phaeozems | | AGRC | 4-7 | Vertic Cambisols |
| | AGRC | 0-4 | | 28 | RNGB | 4-7 | Chromic Vertisols |
| 12 | RNGE | 7-14 | Calcic Fluvisols | | AGRC | 0-4 | Vertic Cambisols |
| | RNGB | 0-4 | Chromic Cambisols | | | 7-14 | Calcic Fluvisols |
| | WETF | 4-7 | Calcic Xerosols | | | | |
| | AGRC | 14-23 | Chromic Vertisols | | | | |
| | URBN | 23-999 | Eutric Nitisols | | | | |

**Appendix: 9 Land use/cover features of selected sub basins of higher sediment load for 1990 LULC**

| Sub basins | HRUs | Land use | Soil type | Slope Range | %Wat. Area | %Sub. Area | Mean annual Sediment Yield ton/ha |
|---|---|---|---|---|---|---|---|
| **1** | 1 | AGRC | Chromic Vertisols | 4-7 | 0.18 | 35.86 | **57.16** |
| | 2 | AGRC | Chromic Vertisols | 0-4 | 2.14 | 65.15 | |
| **2** | 3 | AGRC | Chromic Vertisols | 4-7 | 1.42 | 21.12 | **67.46** |
| | 4 | AGRC | Chromic Vertisols | 0-4 | 2.05 | 30.52 | |
| | 5 | AGRC | Chromic Vertisols | 7-14 | 1.07 | 15.91 | |
| | 6 | AGRC | Leptosols | 23-9999 | 0.62 | 9.2 | |
| | 7 | AGRC | Leptosols | 14-23 | 0.56 | 8.28 | |
| | 8 | AGRC | Leptosols | 7-14 | 0.62 | 9.23 | |
| | 9 | FRST | Calcic Xerosols | 23-9999 | 0.13 | 1.88 | |
| | 10 | FRST | Leptosols | 23-9999 | 0.25 | 3.68 | |
| **9** | 46 | AGRC | Chromic Vertisols | 4-7 | 1.81 | 32.83 | **118.70** |
| | 47 | AGRC | Chromic Vertisols | 7-14 | 1.39 | 25.19 | |
| | 48 | AGRC | Chromic Vertisols | 0-4 | 2.32 | 42.13 | |
| **11** | 51 | AGRC | Chromic Vertisols | 0-4 | 0.97 | 39.09 | **50.27** |
| | 52 | AGRC | Chromic Vertisols | 4-7 | 0.66 | 26.37 | |
| | 53 | WETN | Chromic Vertisols | 0-4 | 0.17 | 6.72 | |
| | 54 | WETN | Chromic Vertisols | 4-7 | 0.08 | 3.21 | |
| | 55 | WETN | Luvic Phaeozems | 4-7 | 0.04 | 1.52 | |
| | 56 | WETN | Luvic Phaeozems | 0-4 | 0.14 | 5.69 | |
| | 57 | FRST | Calcic Xerosols | 7-14 | 0.02 | 0.97 | |
| | 58 | FRST | Calcic Xerosols | 14-23 | 0.02 | 0.81 | |
| | 59 | FRST | Chromic Cambisols | 23-9999 | 0.06 | 2.56 | |
| | 60 | FRST | Chromic Cambisols | 14-23 | 0.03 | 1.27 | |
| | 61 | RNGE | Chromic Cambisols | 23-9999 | 0.15 | 6.2 | |
| | 62 | RNGE | Chromic Cambisols | 14-23 | 0.05 | 1.93 | |
| | 63 | RNGE | Chromic Luvisols | 7-14 | 0.07 | 2.89 | |
| | 64 | RNGE | Chromic Luvisols | 4-7 | 0.04 | 1.79 | |
| **13** | 89 | AGRC | Chromic Vertisols | 7-14 | 2.13 | 22.13 | **97.72** |
| | 90 | AGRC | Chromic Vertisols | 4-7 | 2.44 | 25.44 | |
| | 91 | AGRC | Chromic Vertisols | 0-4 | 2.74 | 28.51 | |
| | 92 | RNGE | Chromic Vertisols | 0-4 | 0.87 | 9.03 | |
| | 93 | RNGE | Chromic Vertisols | 4-7 | 0.58 | 6.04 | |

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|---|---|---|---|---|---|---|---|
| | 94 | URBN | Calcic Xerosols | 4-7 | 0.2 | 2.11 | |
| | 95 | URBN | Calcic Xerosols | 7-14 | 0.29 | 3.04 | |
| | 96 | URBN | Chromic Vertisols | 4-7 | 0.1 | 1.01 | |
| | 97 | URBN | Chromic Vertisols | 0-4 | 0.09 | 0.93 | |
| | 98 | URBN | Chromic Vertisols | 7-14 | 0.14 | 1.41 | |
| **16** | 110 | AGRC | Chromic Vertisols | 4-7 | 0.51 | 36.36 | **54.84** |
| | 111 | AGRC | Chromic Vertisols | 0-4 | 0.8 | 57.27 | |
| | 112 | RNGE | Chromic Luvisols | 23-9999 | 0.03 | 1.94 | |
| | 113 | RNGE | Chromic Luvisols | 7-14 | 0.02 | 1.51 | |
| | 114 | RNGE | Chromic Luvisols | 14-23 | 0.03 | 1.9 | |
| | 115 | RNGE | Chromic Vertisols | 7-14 | 0.01 | 0.93 | |
| | 116 | RNGE | Chromic Vertisols | 0-4 | 0.01 | 0.49 | |
| | 117 | RNGE | Chromic Vertisols | 4-7 | 0.01 | 0.64 | |
| **17** | 118 | AGRC | Chromic Vertisols | 0-4 | 0.89 | 31.41 | **90.13** |
| | 119 | AGRC | Chromic Vertisols | 4-7 | 0.82 | 28.94 | |
| | 120 | AGRC | Chromic Vertisols | 7-14 | 0.61 | 21.66 | |
| | 121 | RNGE | Chromic Cambisols | 14-23 | 0.12 | 4.3 | |
| | 122 | RNGE | Chromic Cambisols | 23-999 | 0.21 | 7.43 | |
| | 123 | RNGE | Chromic Cambisols | 7-14 | 0.09 | 3.33 | |
| | 124 | RNGE | Chromic Vertisols | 4-7 | 0.04 | 1.28 | |
| | 125 | RNGE | Chromic Vertisols | 7-14 | 0.08 | 2.7 | |
| **18** | 126 | AGRC | Chromic Vertisols | 7-14 | 0.65 | 36.57 | **132.05** |
| | 127 | AGRC | Chromic Vertisols | 4-7 | 0.61 | 34.07 | |
| | 128 | AGRC | Chromic Vertisols | 0-4 | 0.54 | 30.39 | |
| **19** | 129 | AGRC | Chromic Vertisols | 7-14 | 0.73 | 27.27 | **120.10** |
| | 130 | AGRC | Chromic Vertisols | 0-4 | 1.06 | 39.87 | |
| | 131 | AGRC | Chromic Vertisols | 4-7 | 0.91 | 33.89 | |
| **24** | 147 | AGRC | Chromic Vertisols | 4-7 | 2.23 | 33.16 | **128.00** |
| | 148 | AGRC | Chromic Vertisols | 0-4 | 2.63 | 39.08 | |
| | 149 | AGRC | Chromic Vertisols | 7-14 | 1.88 | 27.96 | |

**Appendix: 10 Land use/cover features of selected sub basins of lower sediment load for 1990 LULC**

| Sub basins | HRUs | Land use | Soil type | Slope Range | %Wat.Area | %Sub.Area | Mean annual Sediment Yield (ton/ha) |
|---|---|---|---|---|---|---|---|
| **22** | 139 | AGRC | Calcic Fluvisols | 0-4 | 0.09 | 16.78 | **3.31** |
| | 140 | AGRC | Calcic Fluvisols | 7-14 | 0.13 | 24.45 | |
| | 141 | AGRC | Calcic Fluvisols | 4-7 | 0.1 | 19.96 | |
| | 142 | AGRC | Orthic Solonchaks | 14-23 | 0.08 | 15.57 | |
| | 143 | AGRC | Orthic Solonchaks | 7-14 | 0.13 | 24.28 | |
| **29** | 168 | AGRC | Orthic Solonchaks | 0-4 | 0.05 | 31.86 | **0.07** |
| | 169 | AGRC | Orthic Solonchaks | 4-7 | 0.03 | 18.74 | |
| | 170 | WETN | Orthic Solonchaks | 0-4 | 0.05 | 35.05 | |
| **30** | 171 | AGRC | Orthic Solonchaks | 4-7 | 0.01 | 20.45 | **0.08** |
| | 172 | AGRC | Orthic Solonchaks | 0-4 | 0.01 | 54.4 | |
| **31** | 173 | AGRC | Vertic Cambisols | 0-4 | 0.58 | 35.75 | **1.45** |
| | 174 | AGRC | Vertic Cambisols | 4-7 | 0.4 | 24.81 | |
| | 175 | WETN | Orthic Solonchaks | 0-4 | 0.35 | 21.44 | |
| | 176 | RNGB | Chromic Cambisols | 23-9999 | 0.09 | 5.45 | |
| | 177 | RNGB | Chromic Cambisols | 7-14 | 0.09 | 5.72 | |
| | 178 | RNGB | Chromic Cambisols | 14-23 | 0.1 | 6.04 | |
| **33** | 186 | AGRC | Vertic Cambisols | 4-7 | 1.46 | 31.91 | **3.44** |
| | 187 | AGRC | Vertic Cambisols | 0-4 | 2.01 | 43.9 | |
| | 188 | RNGE | Vertic Cambisols | 4-7 | 0.18 | 4 | |
| | 189 | RNGE | Vertic Cambisols | 0-4 | 0.28 | 6.08 | |
| | 190 | RNGE | Vitric Andosols | 0-4 | 0.17 | 3.78 | |
| | 191 | RNGE | Vitric Andosols | 4-7 | 0.11 | 2.43 | |
| | 192 | RNGB | Eutric Nitosols | 0-4 | 0.09 | 1.87 | |
| | 193 | RNGB | Eutric Nitosols | 7-14 | 0.13 | 2.77 | |
| | 194 | RNGB | Eutric Nitosols | 4-7 | 0.11 | 2.49 | |

**Appendix: 11 Land use/cover features of selected sub basins of varied land use/land cover for 1990 LULC**

| Sub basins | HRUs | Land use | Soil type | Slope Range | %Wat.Area | %Sub.Area | Mean annual Sediment Yield (ton/ha) |
|---|---|---|---|---|---|---|---|
| **2** | 3 | AGRC | Chromiv Vertisols | 4-7 | 1.42 | 21.12 | **67.46** |
| | 4 | AGRC | Chromiv Vertisols | 0-4 | 2.05 | 30.52 | |
| | 5 | AGRC | Chromic Vertisols | 7-14 | 1.07 | 15.91 | |
| | 6 | AGRC | Leptosols | 23-9999 | 0.62 | 9.2 | |
| | 7 | AGRC | Leptosols | 14-23 | 0.56 | 8.28 | |
| | 8 | AGRC | Leptosols | 7-14 | 0.62 | 9.23 | |
| | 9 | FRST | Calcic Xerosols | 23-9999 | 0.13 | 1.88 | |
| | 10 | FRST | Leptosols | 23-9999 | 0.25 | 3.68 | |
| **6** | 24 | AGRC | Calcic Xerosols | 7-14 | 0.59 | 12.84 | **29.33** |
| | 25 | AGRC | Calcic Xerosols | 4-7 | 0.4 | 8.71 | |
| | 26 | AGRC | Calcic Xerosols | 0-4 | 0.3 | 6.54 | |
| | 27 | AGRC | Chromic Vertisols | 7-14 | 0.27 | 5.92 | |
| | 28 | AGRC | Chromic Vertisols | 0-4 | 0.55 | 11.83 | |
| | 29 | AGRC | Chromic Vertisols | 4-7 | 0.38 | 8.3 | |
| | 30 | AGRC | Eutic Nitosols | 7-14 | 0.55 | 11.86 | |
| | 31 | AGRC | Eutic Nitosols | 0-4 | 0.37 | 8.08 | |
| | 32 | AGRC | Eutic Nitosols | 4-7 | 0.46 | 10.02 | |
| | 33 | FRST | Calcic Xerosols | 7-14 | 0.11 | 2.35 | |
| | 34 | FRST | Calcic Xerosols | 14-23 | 0.08 | 1.84 | |
| | 35 | FRST | Chromic Cambisols | 23-9999 | 0.1 | 2.06 | |
| | 36 | FRST | Chromic Cambisols | 14-23 | 0.08 | 1.76 | |
| | 37 | RNGE | Calcic Xerosols | 7-14 | 0.09 | 1.86 | |
| | 38 | RNGE | Calcic Xerosols | 14-23 | 0.04 | 0.92 | |
| | 39 | RNGE | Chromic Cambisols | 14-23 | 0.04 | 0.94 | |
| | 40 | RNGE | Chromic Cambisols | 23-9999 | 0.11 | 2.43 | |
| | 41 | RNGE | Eutic Nitosols | 7-14 | 0.07 | 1.41 | |
| | 42 | RNGE | Eutic Nitosols | 4-7 | 0.04 | 0.77 | |
| **11** | 51 | AGRC | Chromiv Vertisols | 0-4 | 0.97 | 39.09 | **50.27** |
| | 52 | AGRC | Chromiv Vertisols | 4-7 | 0.66 | 26.37 | |
| | 53 | WETN | Chromiv Vertisols | 0-4 | 0.17 | 6.72 | |
| | 54 | WETN | Chromiv Vertisols | 4-7 | 0.08 | 3.21 | |
| | 55 | WETN | Luvic Phaeozems | 4-7 | 0.04 | 1.52 | |

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|---|---|---|---|---|---|---|---|
| | 56 | WETN | Luvic Phaeozems | 0-4 | 0.14 | 5.69 | |
| | 57 | FRST | Calcic Xerosols | 7-14 | 0.02 | 0.97 | |
| | 58 | FRST | Calcic Xerosols | 14-23 | 0.02 | 0.81 | |
| | 59 | FRST | Chromic Cambisols | 23-9999 | 0.06 | 2.56 | |
| | 60 | FRST | Chromic Cambisols | 14-23 | 0.03 | 1.27 | |
| | 61 | RNGE | Chromic Cambisols | 23-9999 | 0.15 | 6.2 | |
| | 62 | RNGE | Chromic Cambisols | 14-23 | 0.05 | 1.93 | |
| | 63 | RNGE | Chromic Luvisols | 7-14 | 0.07 | 2.89 | |
| | 64 | RNGE | Chromic Luvisols | 4-7 | 0.04 | 1.79 | |
| **12** | 65 | AGRC | Calcic Fluvisols | 0-4 | 0.08 | 2.12 | **25.49** |
| | 66 | AGRC | Calcic Fluvisols | 4-7 | 0.09 | 2.4 | |
| | 67 | AGRC | Calcic Fluvisols | 7-14 | 0.08 | 1.94 | |
| | 68 | AGRC | Chromic Vertisols | 0-4 | 0.24 | 6.11 | |
| | 69 | AGRC | Chromic Vertisols | 7-14 | 0.17 | 4.28 | |
| | 70 | AGRC | Chromic Vertisols | 4-7 | 0.18 | 4.74 | |
| | 71 | RNGE | Calcic Xerosols | 7-14 | 0.62 | 15.83 | |
| | 72 | RNGE | Calcic Xerosols | 4-7 | 0.36 | 9.23 | |
| | 73 | RNGE | Chromic Cambisols | 23-9999 | 0.51 | 13.18 | |
| | 74 | RNGE | Chromic Cambisols | 14-23 | 0.32 | 8.26 | |
| | 75 | RNGE | Chromic Cambisols | 7-14 | 0.36 | 9.3 | |
| | 76 | WETF | Chromic Luvisols | 7-14 | 0.05 | 1.34 | |
| | 77 | WETF | Chromic Luvisols | 14-23 | 0.08 | 2.11 | |
| | 78 | WETF | Dysric Nitosols | 23-9999 | 0.02 | 0.47 | |
| | 79 | WETF | Dysric Nitosols | 7-14 | 0.03 | 0.82 | |
| | 80 | WETF | Dysric Nitosols | 23-9999 | 0.04 | 0.9 | |
| | 81 | URBN | Calcic Xerosols | 14-23 | 0.12 | 2.99 | |
| | 82 | URBN | Calcic Xerosols | 4-7 | 0.18 | 4.64 | |
| | 83 | URBN | Chromic Vertisols | 7-14 | 0.05 | 1.2 | |
| | 84 | URBN | Chromic Vertisols | 0-4 | 0.04 | 1.05 | |
| | 85 | URBN | Chromic Vertisols | 7-14 | 0.05 | 1.33 | |
| | 86 | URBN | Eutic Nitosols | 0-4 | 0.04 | 1.07 | |
| | 87 | URBN | Eutic Nitosols | 7-14 | 0.08 | 1.97 | |
| | 88 | URBN | Eutic Nitosols | 4-7 | 0.05 | 1.4 | |
| **13** | 89 | AGRC | Chromic Vertisols | 7-14 | 2.13 | 22.13 | **97.72** |
| | 90 | AGRC | Chromic Vertisols | 4-7 | 2.44 | 25.44 | |
| | 91 | AGRC | Chromic Vertisols | 0-4 | 2.74 | 28.51 | |
| | 92 | RNGE | Chromic Vertisols | 0-4 | 0.87 | 9.03 | |
| | 93 | RNGE | Chromic Vertisols | 4-7 | 0.58 | 6.04 | |
| | 94 | URBN | Calcic Xerosols | 4-7 | 0.2 | 2.11 | |

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|---|---|---|---|---|---|---|---|
| | 95 | URBN | Calcic Xerosols | 7-14 | 0.29 | 3.04 | |
| | 96 | URBN | Chromic Vertisols | 4-7 | 0.1 | 1.01 | |
| | 97 | URBN | Chromic Vertisols | 0-4 | 0.09 | 0.93 | |
| | 98 | URBN | Chromic Vertisols | 7-14 | 0.14 | 1.41 | |

**Appendix: 12 <u>Land use/cover features of selected sub basins of higher sediment load for 2013 LULC</u>**

| Sub basins | HRUs | Land use | Soil type | Slope Range | %Wat. Area | %Sub. Area | Mean annual Sediment Yield ton/ha |
|---|---|---|---|---|---|---|---|
| **1** | 1 | RNGE | Chromic Vertisols | 4-7 | 0.14 | 4.31 | **38.51** |
| | 2 | RNGE | Chromic Vertisols | 0-4 | 0.26 | 7.95 | |
| | 3 | RNGB | Chromic Vertisols | 0-4 | 0.47 | 14.29 | |
| | 4 | RNGB | Chromic Vertisols | 4-7 | 0.25 | 7.77 | |
| | 5 | WETF | Chromic Vertisols | 7-14 | 0.06 | 1.74 | |
| | 6 | WETF | Chromic Vertisols | 0-4 | 0.12 | 3.62 | |
| | 7 | WETF | Chromic Vertisols | 4-7 | 0.08 | 2.34 | |
| | 8 | AGRC | Cromic Luvisols | 4-7 | 0.13 | 3.97 | |
| | 9 | AGRC | Cromic Luvisols | 0-4 | 0.36 | 10.87 | |
| | 10 | AGRC | Chromic Vertisols | 0-4 | 0.94 | 28.69 | |
| | 11 | AGRC | Chromic Vertisols | 4-7 | 0.52 | 15.74 | |
| **2** | 12 | RNGE | Calcic Xerosols | 7-14 | 0.17 | 2.6 | **54.07** |
| | 13 | RNGE | Calcic Xerosols | 14-23 | 0.14 | 2.02 | |
| | 14 | RNGE | Calcic Xerosols | 23-9999 | 0.14 | 2.15 | |
| | 15 | RNGE | Chromic Vertisols | 0-4 | 0.35 | 5.21 | |
| | 16 | RNGE | Chromic Vertisols | 4-7 | 0.25 | 3.68 | |
| | 17 | RNGE | Chromic Vertisols | 7-14 | 0.18 | 2.69 | |
| | 18 | RNGB | Chromic Vertisols | 4-7 | 0.33 | 4.95 | |
| | 19 | RNGB | Chromic Vertisols | 7-14 | 0.26 | 3.8 | |
| | 20 | RNGB | Chromic Vertisols | 0-4 | 0.51 | 7.55 | |
| | 21 | WETF | Chromic Vertisols | 7-14 | 0.25 | 3.71 | |
| | 22 | WETF | Chromic Vertisols | 4-7 | 0.27 | 4 | |
| | 23 | WETF | Chromic Vertisols | 0-4 | 0.34 | 5.07 | |
| | 24 | WETF | Leptosols | 14-23 | 0.09 | 1.39 | |
| | 25 | WETF | Leptosols | 23-9999 | 0.11 | 1.63 | |
| | 26 | WETF | Leptosols | 7-14 | 0.13 | 1.92 | |
| | 27 | AGRC | Chromic Vertisols | 0-4 | 1.01 | 14.99 | |

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|---|---|---|---|---|---|---|---|
| | 28 | AGRC | Chromic Vertisols | 7-14 | 0.49 | 7.24 | |
| | 29 | AGRC | Chromic Vertisols | 4-7 | 0.69 | 10.25 | |
| | 30 | AGRC | Leptosols | 14-23 | 0.28 | 4.22 | |
| | 31 | AGRC | Leptosols | 23-9999 | 0.32 | 4.73 | |
| | 32 | AGRC | Leptosols | 7-14 | 0.32 | 4.73 | |
| **9** | 105 | RNGE | Chromic Vertisols | 4-7 | 0.27 | 4.89 | **82.92** |
| | 106 | RNGE | Chromic Vertisols | 7-14 | 0.29 | 5.23 | |
| | 107 | RNGE | Chromic Vertisols | 0-4 | 0.28 | 5.02 | |
| | 108 | RNGB | Chromic Vertisols | 0-4 | 0.47 | 8.46 | |
| | 109 | RNGB | Chromic Vertisols | 7-14 | 0.24 | 4.3 | |
| | 110 | RNGB | Chromic Vertisols | 4-7 | 0.33 | 5.91 | |
| | 111 | WETF | Chromic Vertisols | 7-14 | 0.3 | 5.52 | |
| | 112 | WETF | Chromic Vertisols | 0-4 | 0.33 | 6.03 | |
| | 113 | WETF | Chromic Vertisols | 4-7 | 0.3 | 5.52 | |
| | 114 | AGRC | Chromic Vertisols | 4-7 | 1.12 | 20.29 | |
| | 115 | AGRC | Chromic Vertisols | 0-4 | 1.54 | 28.03 | |
| **11** | 124 | FRSE | Chromic Cambisols | 14-23 | 0.07 | 2.69 | **45.93** |
| | 125 | FRSE | Chromic Cambisols | 23-9999 | 0.12 | 4.9 | |
| | 126 | FRSD | Chromic Vertisols | 4-7 | 0.04 | 1.65 | |
| | 127 | FRSD | Chromic Vertisols | 0-4 | 0.09 | 3.55 | |
| | 128 | FRSD | Luvic Phaeozems | 4-7 | 0.01 | 0.4 | |
| | 129 | FRSD | Luvic Phaeozems | 0-4 | 0.03 | 1.1 | |
| | 130 | RNGB | Chromic Vertisols | 0-4 | 0.17 | 6.67 | |
| | 131 | RNGB | Chromic Vertisols | 4-7 | 0.09 | 3.7 | |
| | 132 | RNGB | Luvic Phaeozems | 0-4 | 0.12 | 4.73 | |
| | 133 | AGRC | Chromic Vertisols | 0-4 | 1.06 | 42.57 | |
| | 134 | AGRC | Chromic Vertisols | 4-7 | 0.73 | 29.54 | |
| **13** | 166 | FRST | Chromic Vertisols | 4-7 | 0.42 | 4.33 | **79.36** |
| | 167 | FRST | Chromic Vertisols | 0-4 | 0.5 | 5.23 | |
| | 168 | RNGB | Chromic Vertisols | 0-4 | 0.27 | 2.81 | |
| | 169 | RNGB | Chromic Vertisols | 4-7 | 0.26 | 2.72 | |
| | 170 | RNGB | Chromic Vertisols | 7-14 | 0.3 | 3.13 | |
| | 171 | WETF | Chromic Vertisols | 0-4 | 0.36 | 3.79 | |
| | 172 | WETF | Chromic Vertisols | 7-14 | 0.25 | 2.56 | |
| | 173 | WETF | Chromic Vertisols | 4-7 | 0.29 | 3.06 | |
| | 174 | AGRC | Chromic Vertisols | 7-14 | 1.46 | 15.18 | |
| | 175 | AGRC | Chromic Vertisols | 0-4 | 1.87 | 19.45 | |
| | 176 | AGRC | Chromic Vertisols | 4-7 | 1.66 | 17.25 | |
| | 177 | URBN | Calcic Xerosols | 4-7 | 0.24 | 2.52 | |

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|---|---|---|---|---|---|---|---|
| | 178 | URBN | Calcic Xerosols | 0-4 | 0.2 | 2.05 | |
| | 179 | URBN | Calcic Xerosols | 7-14 | 0.34 | 3.54 | |
| | 180 | URBN | Chromic Vertisols | 0-4 | 0.3 | 3.15 | |
| | 181 | URBN | Chromic Vertisols | 7-14 | 0.36 | 3.75 | |
| | 182 | URBN | Chromic Vertisols | 4-7 | 0.32 | 3.32 | |
| **16** | 221 | FRST | Chromic Vertisols | 0-4 | 0.14 | 10.14 | **45.72** |
| | 222 | FRST | Chromic Vertisols | 4-7 | 0.07 | 5.33 | |
| | 223 | RNGB | Chromic Vertisols | 0-4 | 0.06 | 4.56 | |
| | 224 | RNGB | Chromic Vertisols | 4-7 | 0.04 | 2.99 | |
| | 225 | AGRC | Chromic Vertisols | 4-7 | 0.44 | 31.59 | |
| | 226 | AGRC | Chromic Vertisols | 0-4 | 0.66 | 46.9 | |
| **17** | 227 | FRST | Chromic Cambisols | 23-9999 | 0.05 | 1.69 | **87.55** |
| | 228 | FRST | Chromic Vertisols | 0-4 | 0.1 | 3.67 | |
| | 229 | FRST | Chromic Vertisols | 4-7 | 0.08 | 2.97 | |
| | 230 | RNGB | Chromic Vertisols | 0-4 | 0.11 | 3.74 | |
| | 231 | RNGB | Chromic Vertisols | 4-7 | 0.1 | 3.63 | |
| | 232 | RNGB | Chromic Vertisols | 7-14 | 0.09 | 3.2 | |
| | 233 | AGRC | Chromic Vertisols | 7-14 | 0.66 | 23.35 | |
| | 234 | AGRC | Chromic Vertisols | 0-4 | 0.86 | 30.45 | |
| | 235 | AGRC | Chromic Vertisols | 4-7 | 0.82 | 28.81 | |
| **18** | 236 | RNGB | Chromic Vertisols | 7-14 | 0.07 | 4.1 | **100.58** |
| | 237 | RNGB | Chromic Vertisols | 4-7 | 0.06 | 3.32 | |
| | 238 | RNGB | Chromic Vertisols | 0-4 | 0.05 | 2.71 | |
| | 239 | WETF | Chromic Vertisols | 7-14 | 0.03 | 1.48 | |
| | 240 | WETF | Chromic Vertisols | 0-4 | 0.02 | 1.18 | |
| | 241 | WETF | Chromic Vertisols | 4-7 | 0.02 | 1.22 | |
| | 242 | WETF | Dystric Nitosols | 7-14 | 0.01 | 0.8 | |
| | 243 | WETF | Dystric Nitosols | 14-23 | 0.02 | 1.33 | |
| | 244 | WETF | Dystric Nitosols | 23-9999 | 0.02 | 1.14 | |
| | 245 | AGRC | Chromic Vertisols | 0-4 | 0.45 | 25.49 | |
| | 246 | AGRC | Chromic Vertisols | 4-7 | 0.51 | 28.52 | |
| | 247 | AGRC | Chromic Vertisols | 7-14 | 0.54 | 30.21 | |
| **19** | 248 | FRST | Chromic Vertisols | 0-4 | 0.08 | 2.83 | **102.76** |
| | 249 | FRST | Chromic Vertisols | 4-7 | 0.06 | 2.09 | |
| | 250 | FRST | Chromic Vertisols | 7-14 | 0.04 | 1.38 | |
| | 251 | RNGB | Chromic Vertisols | 7-14 | 0.05 | 1.71 | |
| | 252 | RNGB | Chromic Vertisols | 0-4 | 0.08 | 2.81 | |
| | 253 | RNGB | Chromic Vertisols | 4-7 | 0.07 | 2.44 | |
| | 254 | WETF | Chromic Vertisols | 7-14 | 0.13 | 4.9 | |

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|---|---|---|---|---|---|---|---|
| | 255 | WETF | Chromic Vertisols | 4-7 | 0.1 | 3.87 | |
| | 256 | WETF | Chromic Vertisols | 0-4 | 0.1 | 3.68 | |
| | 257 | AGRC | Chromic Vertisols | 0-4 | 0.82 | 30.52 | |
| | 258 | AGRC | Chromic Vertisols | 4-7 | 0.68 | 25.58 | |
| | 259 | AGRC | Chromic Vertisols | 7-14 | 0.53 | 19.68 | |
| **24** | 309 | FRST | Chromic Vertisols | 0-4 | 0.41 | 6.1 | **103.23** |
| | 310 | FRST | Chromic Vertisols | 4-7 | 0.3 | 4.49 | |
| | 311 | RNGB | Chromic Vertisols | 4-7 | 0.26 | 3.85 | |
| | 312 | RNGB | Chromic Vertisols | 0-4 | 0.34 | 5.1 | |
| | 313 | WETF | Chromic Vertisols | 7-14 | 0.5 | 7.43 | |
| | 314 | WETF | Chromic Vertisols | 0-4 | 0.57 | 8.5 | |
| | 315 | WETF | Chromic Vertisols | 4-7 | 0.51 | 7.64 | |
| | 316 | AGRC | Chromic Vertisols | 4-7 | 1.26 | 18.78 | |
| | 317 | AGRC | Chromic Vertisols | 0-4 | 1.45 | 21.65 | |
| | 318 | AGRC | Chromic Vertisols | 7-14 | 1.08 | 16.02 | |

**Appendix: 13 <u>Land use/cover features of selected sub basins of lower sediment load for 2013 LULC</u>**

| Sub basins | HRUs | Land use | Soil type | Slope Range | %Wat.Area | %Sub.Area | Mean annual Sediment Yield ton/ha |
|---|---|---|---|---|---|---|---|
| **22** | 282 | FRST | Calcic Fluvisols | 4-7 | 0.01 | 1.9 | **1.69** |
| | 283 | FRST | Calcic Fluvisols | 0-4 | 0.01 | 1.97 | |
| | 284 | FRST | Calcic Fluvisols | 7-14 | 0.01 | 1.34 | |
| | 285 | FRST | Eutric Cambisols | 7-14 | 0 | 0.65 | |
| | 286 | FRST | Eutric Cambisols | 23-9999 | 0.01 | 1.53 | |
| | 287 | FRST | Eutric Cambisols | 14-23 | 0 | 0.74 | |
| | 288 | RNGB | Calcic Fluvisols | 7-14 | 0.01 | 1.77 | |
| | 289 | RNGB | Calcic Fluvisols | 0-4 | 0.01 | 1.02 | |
| | 290 | RNGB | Calcic Fluvisols | 4-7 | 0.01 | 1.35 | |
| | 291 | RNGB | Orthic Solonchaks | 7-14 | 0.01 | 2.72 | |
| | 292 | WETF | Calcic Fluvisols | 4-7 | 0.01 | 2.56 | |
| | 293 | WETF | Calcic Fluvisols | 7-14 | 0.02 | 3.84 | |
| | 294 | WETF | Orthic Solonchaks | 7-14 | 0.03 | 5.34 | |
| | 295 | WETF | Orthic Solonchaks | 14-23 | 0.02 | 3.77 | |
| | 296 | AGRC | Calcic Fluvisols | 4-7 | 0.08 | 14.78 | |

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|---|---|---|---|---|---|---|---|
| | 297 | AGRC | Calcic Fluvisols | 7-14 | 0.1 | 18.31 | |
| | 298 | AGRC | Calcic Fluvisols | 0-4 | 0.06 | 12.42 | |
| | 299 | AGRC | Orthic Solonchaks | 42930 | 0.08 | 15.62 | |
| | 300 | AGRC | Orthic Solonchaks | 14-23 | 0.05 | 9.87 | |
| **29** | 353 | RNGB | Orthic Solonchaks | 0-4 | 0.02 | 16.05 | **0.13** |
| | 354 | RNGB | Orthic Solonchaks | 4-7 | 0.01 | 6.13 | |
| | 355 | AGRC | Orthic Solonchaks | 0-4 | 0.06 | 43.26 | |
| | 356 | AGRC | Orthic Solonchaks | 4-7 | 0.03 | 21.24 | |
| **30** | 357 | FRST | Orthic Solonchaks | 4-7 | 0 | 2.02 | **0.11** |
| | 358 | FRST | Orthic Solonchaks | 0-4 | 0 | 4.48 | |
| | 359 | FRSD | Orthic Solonchaks | 0-4 | 0 | 6.86 | |
| | 360 | AGRC | Orthic Solonchaks | 4-7 | 0 | 16.92 | |
| | 361 | AGRC | Orthic Solonchaks | 0-4 | 0.01 | 45.57 | |
| | 362 | SWRN | Orthic Solonchaks | 4-7 | 0 | 2.17 | |
| | 363 | SWRN | Orthic Solonchaks | 0-4 | 0 | 4.22 | |
| **31** | 364 | FRST | Chromic Cambisols | 7-14 | 0.02 | 1.29 | **0.76** |
| | 365 | FRST | Chromic Cambisols | 14-23 | 0.03 | 1.85 | |
| | 366 | FRST | Chromic Cambisols | 23-9999 | 0.03 | 1.72 | |
| | 367 | FRST | Orthic Solonchaks | 0-4 | 0.06 | 3.48 | |
| | 368 | RNGB | Orthic Solonchaks | 0-4 | 0.03 | 2.06 | |
| | 369 | RNGB | Orthic Solonchaks | 4-7 | 0.01 | 0.58 | |
| | 370 | RNGB | Vertic Cambisols | 0-4 | 0.09 | 5.35 | |
| | 371 | RNGB | Vertic Cambisols | 4-7 | 0.06 | 3.78 | |
| | 372 | WETF | Chromic Cambisols | 14-23 | 0.03 | 2.11 | |
| | 373 | WETF | Chromic Cambisols | 23-9999 | 0.03 | 2 | |
| | 374 | WETF | Chromic Cambisols | 7-14 | 0.03 | 1.99 | |
| | 375 | AGRC | Orthic Solonchaks | 0-4 | 0.27 | 16.9 | |
| | 376 | AGRC | Orthic Solonchaks | 4-7 | 0.08 | 4.92 | |
| | 377 | AGRC | Vertic Cambisols | 4-7 | 0.34 | 21.17 | |
| | 378 | AGRC | Vertic Cambisols | 0-4 | 0.5 | 30.71 | |
| **33** | 389 | RNGB | Vertic Cambisols | 4-7 | 0.24 | 5.35 | **1.78** |
| | 390 | RNGB | Vertic Cambisols | 0-4 | 0.32 | 6.95 | |
| | 391 | AGRC | Vertic Cambisols | 0-4 | 2.33 | 51.02 | |
| | 392 | AGRC | Vertic Cambisols | 4-7 | 1.66 | 36.27 | |

**Appendix: 14** **Land use/cover features of selected sub basins of varied land use/land cover for 2013 LULC**

| Sub basins | HRUs | land use | Soil type | Slope Range | %Wat.Area | %Sub.Area | Mean annual Sediment Yield ton/ha |
|---|---|---|---|---|---|---|---|
| **2** | 12 | RNGE | Calcic Xerosols | 7-14 | 0.17 | 2.6 | **54.07** |
| | 13 | RNGE | Calcic Xerosols | 14-23 | 0.14 | 2.02 | |
| | 14 | RNGE | Calcic Xerosols | 23-9999 | 0.14 | 2.15 | |
| | 15 | RNGE | Chromic Vertisols | 0-4 | 0.35 | 5.21 | |
| | 16 | RNGE | Chromic Vertisols | 4-7 | 0.25 | 3.68 | |
| | 17 | RNGE | Chromic Vertisols | 7-14 | 0.18 | 2.69 | |
| | 18 | RNGB | Chromic Vertisols | 4-7 | 0.33 | 4.95 | |
| | 19 | RNGB | Chromic Vertisols | 7-14 | 0.26 | 3.8 | |
| | 20 | RNGB | Chromic Vertisols | 0-4 | 0.51 | 7.55 | |
| | 21 | WETF | Chromic Vertisols | 7-14 | 0.25 | 3.71 | |
| | 22 | WETF | Chromic Vertisols | 4-7 | 0.27 | 4 | |
| | 23 | WETF | Chromic Vertisols | 0-4 | 0.34 | 5.07 | |
| | 24 | WETF | Leptosols | 14-23 | 0.09 | 1.39 | |
| | 25 | WETF | Leptosols | 23-9999 | 0.11 | 1.63 | |
| | 26 | WETF | Leptosols | 7-14 | 0.13 | 1.92 | |
| | 27 | AGRC | Chromic Vertisols | 0-4 | 1.01 | 14.99 | |
| | 28 | AGRC | Chromic Vertisols | 7-14 | 0.49 | 7.24 | |
| | 29 | AGRC | Chromic Vertisols | 4-7 | 0.69 | 10.25 | |
| | 30 | AGRC | Leptosols | 14-23 | 0.28 | 4.22 | |
| | 31 | AGRC | Leptosols | 23-9999 | 0.32 | 4.73 | |
| | 32 | AGRC | Leptosols | 7-14 | 0.32 | 4.73 | |
| **6** | 74 | RNGE | Calcic Xerosols | 7-14 | 0.23 | 5.01 | **22.36** |
| | 75 | RNGE | Calcic Xerosols | 4-7 | 0.13 | 2.74 | |
| | 76 | RNGE | Eutic Nitosols | 7-14 | 0.11 | 2.41 | |
| | 77 | RNGE | Eutic Nitosols | 4-7 | 0.08 | 1.75 | |
| | 78 | RNGE | Eutic Nitosols | 0-4 | 0.05 | 1.17 | |
| | 79 | RNGB | Calcic Xerosols | 4-7 | 0.07 | 1.52 | |
| | 80 | RNGB | Calcic Xerosols | 7-14 | 0.13 | 2.75 | |
| | 81 | RNGB | Chromiv Vertisols | 0-4 | 0.11 | 2.4 | |
| | 82 | RNGB | Chromiv Vertisols | 7-14 | 0.07 | 1.44 | |
| | 83 | RNGB | Chromiv Vertisols | 4-7 | 0.08 | 1.69 | |
| | 84 | WETF | Calcic Xerosols | 4-7 | 0.2 | 4.36 | |

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|---|---|---|---|---|---|---|---|
| | 85 | WETF | Calcic Xerosols | 7-14 | 0.11 | 2.43 | |
| | 86 | WETF | Eutic Nitosols | 7-14 | 0.1 | 2.09 | |
| | 87 | WETF | Eutic Nitosols | 4-7 | 0.14 | 3.09 | |
| | 88 | AGRC | Calcic Xerosols | 0-4 | 0.68 | 14.73 | |
| | 89 | AGRC | Calcic Xerosols | 4-7 | 0.43 | 9.23 | |
| | 90 | AGRC | Chromic Vertisols | 0-4 | 0.44 | 9.45 | |
| | 91 | AGRC | Chromic Vertisols | 4-7 | 0.31 | 6.66 | |
| | 92 | AGRC | Chromic Vertisols | 7-14 | 0.23 | 4.94 | |
| | 93 | AGRC | Eutic Nitosols | 0-4 | 0.26 | 5.73 | |
| | 94 | AGRC | Eutic Nitosols | 4-7 | 0.32 | 6.97 | |
| | 95 | AGRC | Eutic Nitosols | 7-14 | 0.4 | 8.63 | |
| **11** | 124 | FRSE | Chromic Cambisols | 14-23 | 0.07 | 2.69 | **45.93** |
| | 125 | FRSE | Chromic Cambisols | 23-9999 | 0.12 | 4.9 | |
| | 126 | FRSD | Chromic Vertisols | 4-7 | 0.04 | 1.65 | |
| | 127 | FRSD | Chromic Vertisols | 0-4 | 0.09 | 3.55 | |
| | 128 | FRSD | Luvic Phaeozems | 4-7 | 0.01 | 0.4 | |
| | 129 | FRSD | Luvic Phaeozems | 0-4 | 0.03 | 1.1 | |
| | 130 | RNGB | Chromic Vertisols | 0-4 | 0.17 | 6.67 | |
| | 131 | RNGB | Chromic Vertisols | 4-7 | 0.09 | 3.7 | |
| | 132 | RNGB | Luvic Phaeozems | 0-4 | 0.12 | 4.73 | |
| | 133 | AGRC | Chromic Vertisols | 0-4 | 1.06 | 42.57 | |
| | 134 | AGRC | Chromic Vertisols | 4-7 | 0.73 | 29.54 | |
| **12** | 135 | RNGE | Calcic Fluvisols | 7-14 | 0.05 | 1.25 | **39.46** |
| | 136 | RNGE | Calcic Fluvisols | 0-4 | 0.04 | 1.03 | |
| | 137 | RNGE | Calcic Fluvisols | 4-7 | 0.05 | 0.29 | |
| | 138 | RNGE | Chromic Cambisols | 7-14 | 0.04 | 1.05 | |
| | 139 | RNGE | Chromic Cambisols | 14-23 | 0.04 | 1.16 | |
| | 140 | RNGE | Chromic Cambisols | 23-9999 | 0.08 | 2.17 | |
| | 141 | RNGB | Calcic Xerosols | 7-14 | 0.03 | 0.74 | |
| | 142 | URBN | Calcic Xerosols | 4-7 | 0.02 | 0.51 | |
| | 143 | URBN | Calcic Xerosols | 0-4 | 0.02 | 0.46 | |
| | 144 | URBN | Chromic Cambisols | 14-23 | 0.03 | 0.67 | |
| | 145 | URBN | Chromic Cambisols | 7-14 | 0.03 | 0.82 | |
| | 146 | URBN | Chromic Cambisols | 23-9999 | 0.03 | 0.66 | |
| | 147 | URBN | Chromic Vertisols | 0-4 | 0.03 | 0.84 | |
| | 148 | URBN | Chromic Vertisols | 4-7 | 0.03 | 0.84 | |
| | 149 | URBN | Chromic Vertisols | 7-14 | 0.05 | 1.17 | |
| | 150 | WETF | Chromic Cambisols | 7-14 | 0.06 | 1.63 | |
| | 151 | WETF | Chromic Cambisols | 14-23 | 0.08 | 1.95 | |

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|---|---|---|---|---|---|---|---|
| | 152 | WETF | Chromic Cambisols | 23-9999 | 0.15 | 3.84 | |
| | 153 | AGRC | Chromic Cambisols | 23-9999 | 0.29 | 7.35 | |
| | 154 | AGRC | Chromic Cambisols | 14-23 | 0.22 | 5.72 | |
| | 155 | AGRC | Chromic Cambisols | 7-14 | 0.26 | 6.6 | |
| | 156 | AGRC | Chromic Vertisols | 7-14 | 0.33 | 8.56 | |
| | 157 | AGRC | Chromic Vertisols | 4-7 | 0.29 | 7.41 | |
| | 158 | AGRC | Chromic Vertisols | 0-4 | 0.32 | 8.34 | |
| | 159 | URBN | Calcic Xerosols | 7-14 | 0.43 | 11.07 | |
| | 160 | URBN | Calcic Xerosols | 4-7 | 0.24 | 6.28 | |
| | 161 | URBN | Chromic Vertisols | 7-14 | 0.13 | 3.22 | |
| | 162 | URBN | Chromic Vertisols | 4-7 | 0.1 | 2.67 | |
| | 163 | URBN | Chromic Vertisols | 0-4 | 0.09 | 2.22 | |
| | 164 | URBN | Eutric Nitosols | 7-14 | 0.18 | 4.68 | |
| | 165 | URBN | Eutric Nitosols | 4-7 | 0.12 | 3.18 | |
| **13** | 166 | FRST | Chromic Vertisols | 4-7 | 0.42 | 4.33 | **79.36** |
| | 167 | FRST | Chromic Vertisols | 0-4 | 0.5 | 5.23 | |
| | 168 | RNGB | Chromic Vertisols | 0-4 | 0.27 | 2.81 | |
| | 169 | RNGB | Chromic Vertisols | 4-7 | 0.26 | 2.72 | |
| | 170 | RNGB | Chromic Vertisols | 7-14 | 0.3 | 3.13 | |
| | 171 | WETF | Chromic Vertisols | 0-4 | 0.36 | 3.79 | |
| | 172 | WETF | Chromic Vertisols | 7-14 | 0.25 | 2.56 | |
| | 173 | WETF | Chromic Vertisols | 4-7 | 0.29 | 3.06 | |
| | 174 | AGRC | Chromic Vertisols | 7-14 | 1.46 | 15.18 | |
| | 175 | AGRC | Chromic Vertisols | 0-4 | 1.87 | 19.45 | |
| | 176 | AGRC | Chromic Vertisols | 4-7 | 1.66 | 17.25 | |
| | 177 | URBN | Calcic Xerosols | 4-7 | 0.24 | 2.52 | |
| | 178 | URBN | Calcic Xerosols | 0-4 | 0.2 | 2.05 | |
| | 179 | URBN | Calcic Xerosols | 7-14 | 0.34 | 3.54 | |
| | 180 | URBN | Chromic Vertisols | 0-4 | 0.3 | 3.15 | |
| | 181 | URBN | Chromic Vertisols | 7-14 | 0.36 | 3.75 | |
| | 182 | URBN | Chromic Vertisols | 4-7 | 0.32 | 3.32 | |